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Vegetation of Wilmington Shrub Prairie Nature Preserve, Will County, Illinois

John E. Ebinger*, Loy R. Phillippe, and Paul B. Marcum
Illinois Natural History Survey, 1816 South Oak Street, Champaign, Illinois 61820
*corresponding author (jeebinger@eiu.edu)

ABSTRACT

Wilmington Shrub Prairie Nature Preserve is located in the southwestern corner of Will County about 4 km east of Braidwood in the Kankakee Sand Area Section of the Grand Prairie Natural Division. Extensive areas of the preserve have been degraded by past grazing, peat fires, and parts were probably cultivated before the land was purchased by the Illinois Department of Natural Resources in 1989. Small sections of the preserve still contain native vegetation of high natural quality. On both dry-mesic "black soil" prairies studied *Helianthus mollis* (downy sunflower), *Parthenium integrifolium* (America feverfew), and *Schizachyrium scoparium* (little bluestem) dominated (highest importance values). Overall, less than 25 species on each prairie had an I.V. greater than 2.5 with 61species recorded in the plots of one prairie and 102 on the second. *Spiraea tomentosa* (hardhack), *Rubus hispidus* (swampy dewberry), and *Onoclea sensibilis* (sensitive fern) dominated the two shrub prairies surveyed with mosses the common ground cover. The sedge meadow was dominated by *Carex haydenii/stricta*, *Onoclea sensibilis*, *Calamagrostis canadensis* (bluejoint grass), and *Thelypteris palustris* (marsh fern). *Cephalanthus occidentalis* (buttonbush) dominated the shrub swamp. Of the 358 vascular plant taxa found, 32 were exotics.

Key Words: dry to dry-mesic prairie, Illinois, Kankakee sand deposits, sedge meadow, shrub prairie, shrub swamp.

INTRODUCTION

Sand deposits are relatively common in the northern half of Illinois, accounting for nearly 5% of the land surface. These deposits, the result of erosion events associated with Wisconsin glaciation, were formed about 14,500 years ago (King 1981; Schwegman 1973; Willman and Frye 1970). The Kankakee sand deposits in northeastern Illinois are the most extensive in the state, extending from Newton County, Indiana west through large parts of Iroquois, Kankakee, Will, and Grundy counties, Illinois. These deposits remained after glacial lakes were drained as glacial moraines and ice dams were breached resulting in the Kankakee Torrent (Willman 1973). This torrent carried large amounts of sand and gravel down the Kankakee and Illinois River valleys into central Illinois south of present day Hennepin, Illinois (Schwegman 1973).

The early studies of Illinois sand deposits by Hart and Gleason (1907), Gleason (1910), and Vestal (1913) mostly discuss the species associated with dry to mesic sand prairies and sand savannas. Also, more recent studies in Illinois sand deposits have mostly been concerned with dry sand prairie and sand savanna communities as these habitats are

abundant, being less suitable for cultivation. Overall, dry habitats are characteristic of sand deposits, and the commonly associated species are those adapted to xeric conditions (White and Madany 1978). Plant communities of sand deposits, however, are extremely diverse and also include many differed wet and wet-mesic community types. In Will County, these wetland communities are found on the extensive outwash plains and old lake beds of Wisconsian glaciation. In these wet to mesic communities the soil has a high organic content resulting in a dark A horizon, while some of the dominant grass species (Poaceae) are replaced by sedges and rushes (Cyperaceae and Juncaceae).

Wet and mesic sand prairie communities are common in some of the nature preserves in Will County Illinois where sand areas are interspersed with "black soil" communities in some preserves and sand dunes, which are usually associated with sand deposits, are uncommon or absent. One of these preserves, Wilmington Shrub Prairie Nature Preserve (WSPNP) contains wetland communities on both fine sand and sandy loam soils. The present study was undertaken to determine vascular plant species composition, vegetation structure, and floristic quality of the major natural plant communities on this Preserve.

DESCRIPTION OF THE STUDY AREA

The 72 ha WSPNP is located in the southwestern corner of Will County about 4 km east of Braidwood, and 20 km south of Joliet (SW1/4 S2 NW1/4 S11 T32N R10E; 41.27934°N, -88.166576°W). Presently owned by the Illinois Department of Natural Resources (IDNR), the Preserve is located in the Kankakee Sand Area Section of the Grand Prairie Natural Division (Schwegman 1973). Dedicated in 1989, this Preserve contains remnants of dry-mesic to mesic "black soil" prairie, dry-mesic to mesic sand prairie, sedge meadows, marshes, sand savannas, shrub prairies, and shrub swamps (McFall and Karnes 1995). Extensive areas of the preserve have been degraded by past grazing and farming, and it is likely that extensive peat fires occurred in bog and sedge meadow communities in the mid 1900s. Small parts of the preserve still contain plant communities of high natural quality.

The Preserve is situated near the edge of former glacial Lake Wauponsee that drained during the Kankakee Torrent leaving sandy beaches and near shore sand deposits (Willman and Frye 1970). Characteristic sand savanna and sand prairie vegetation became established during the Hypsithermal period about 8,000 years ago (King 1981). The soils of the Preserve are mostly fine sandy loam (Gilford and Grundy) that are poorly drained and relatively high in organic material. Some Watseka and Ade loamy fine sand are also present on slightly higher ground. These fine sands developed from windblown sediments, are well drained, and relatively low in organic material (Hanson 2004). The climate is continental with warm summers and cold winters. Mean annual precipitation is 98.0 cm, with May having the highest rainfall (11.5 cm). Mean annual temperature is 9.9°C with the hottest month being July (average of 23.6°C), and the coldest being January (average of -5.7°C). Frost-free days range from 141 to 206, with the average being 174 days per year (Midwestern Regional Climate Center 2009; Kankakee, Illinois).

METHODS

Floristic Composition

The Preserve was visited six to ten times each year throughout the growing seasons of 2007 to 2009. During these visits voucher specimens were collected and deposited in the herbarium of the Illinois Natural History Survey, Champaign, Illinois (ILLS). The designation of exotic species follows Gleason and Cronquist (1991), Mohlenbrock (2002), and Taft et al. (1997). Nomenclature follows Mohlenbrock (2002).

Sampling

In mid-summer of 2009 transects were located randomly along cardinal compass directions within two mesic prairies, two shrub prairies, and a sedge meadow. Within each of these communities, two transects were located (n = 50 plots). Along each transect, 1m^2 quadrats were located alternately along each transect. A random numbers table was used to determine the distance (0 to 9 m) a quadrat was located from the transect line. Species cover was determined using the Daubenmire (1959) cover class system as modified by Bailey and Poulton (1968). The modified Daubenmire cover scale is as follows: class 1 = 0 to 1%; class 2 = >1 to 5%; class 3 = >5 to 25%; class 4 = >25 to 50%; class 5 = >50 to 75%; class 6 = >75 to 95%; class 7 = >95 to 100%. Only ground layer species rooted within the quadrat frame were recorded. Mean cover was determined for each taxon using the mid-point values for each cover class, while Importance Value (I.V.) was calculated by summing relative cover and relative frequency.

The shrub swamp was sampled in late-summer of 2010 by randomly locating three transects 20 m long in various aged parts of the swamp based on the average size of the larger stems observed (swamp margin, mature swamp, old-age swamp). Along each transect five circular plots 0.001 ha (10 m^2) were located at 5 m intervals, and the number of plants of *Cephalanthus occidentalis* (buttonbush), and the number of individuals stems by basal diameter class was determined. From this data the density (plants/ha) of plants and the number of stems (stems/ha) by basal diameter classes determined.

RESULTS

Floristic Composition

The preserve supported a total of 358 vascular plant taxa in 81 families (Appendix I). Ferns, fern-allies, and gymnosperms were represented by 11 taxa in 7 families. Of the remaining taxa, 104 were monocots in 12 families, and 243 were dicots in 62 families. Non-native (exotic) species accounted for 32 taxa, about 8% of the species collected. Predominant plant families were Asteraceae (65 species), Poaceae (44), and Cyperaceae (29). The only state endangered species found was *Platanthera clavellata* (wood orchid). No state threatened species were encountered (Illinois Endangered Species Protection Board 2005).

Dry to Dry-Mesic Prairie

Two small dry to dry mesic "black soil" prairies were surveyed, one at the northwest corner of the Preserve (North Edge Prairie) (41.27989°N, -88.16562°W), the other in the south part of the Preserve (South Central Prairie) (41.27446°N, -88.16428°W). Both are situated on fine sandy loam soils high in organic material. On both prairies the dominant

grass was *Schizachyrium scoparium* (little bluestem) with *Sorghastrum nutans* (Indian grass) ranging from fifth to eight in I.V. while *Andropogon gerardii* (big bluestem) was present but not common (Table 1). *Schizachyrium scoparium* was distributed throughout the prairie as indicated by its high frequency, the other two species being less common. On both prairies *Helianthus mollis* (downy sunflower) and *Parthenium integrifolium* (America feverfew) were among the top three species in I.V. Other common forbs encountered were *Euthamia gymnospermoides* (viscid grass-leaved goldenrod), *Coreopsis tripteris* (tall tickseed), *Solidago missouriensis* (Missouri goldenrod), *Potentilla simplex* (common cinquefoil), and *Rubus flagellaris* (common dewberry). Overall, less than 25 species on each prairie had an I.V. greater than 2.5 (possible 200), though 61 species were recorded for South Central Prairie and 102 were recorded for North Edge Prairie (Table 1). Only six exotic species were recorded in the plots, *Poa pratensis* (Kentucky blue grass), *Achillea millefolium* (yarrow), and *Rumex acetosella* (sour dock) being the most common with Importance Values between 2.5 and 8.2 (Table 1).

Shrub Prairie

Two small shrub prairies were surveyed, one at the southeast corner of the Preserve (East Shrub Prairie) (41.27183°N, -88.15765°W), the other about 250 m to the northwest in the southwest corner of the Preserve (West Shrub Prairie) (41.27307°N, -88.16689°W). At the time of the survey the East Shrub prairie had recently been brush-hogged. The vegetation survey was conducted in an undisturbed narrow section along the southern edge of this shrub prairie. Both shrub prairies were on wet to mesic, acidic sandy soils high in organic material and both were dominated by prairie shrubs, forbs, and a few grasses with mosses usually forming part of the ground-layer (White and Madany 1978). Common woody species encountered were *Spiraea tomentosa* (hardhack), *Rubus hispidus* (swampy dewberry), and *Aronia melanocarpa* (black chokeberry). The ferns *Onoclea sensibilis* (sensitive fern) and *Osmunda regalis* (royal fern) were the dominant herbaceous species encountered (Table 2). A few prairie forbs were common, many species scattered through the shrub prairie, but mostly in low numbers. Few prairie grasses were encountered, although *Andropogon gerardii* was found on the southeastern shrub prairie (I.V. of 8.6). Other grass-like plants included eight species sedges (Cyperaceae) and two rushes (Juncaceae). Overall, 49 species were encountered in West Shrub Prairie and 51 species from East Shrub Prairie. Three exotic species were found, all in very low numbers with *Poa pratensis* being the most common (I.V. of 1.8).

Mosses were relatively common in the ground layer in the shrub prairies. On East Shrub Prairie the I.V. for bryophytes was 22.0 (possible 200), on West Shrub Prairie the I.V. was only 2.9. Parts of the West Shrub Prairie had a higher concentrations of bryophytes, but in the area we surveyed mosses were not important. Species encountered included: *Aulacomnium palustre* (Hedw.) Schwaegr., *Helodium paludosum* (Sull.) Aust., *Leucobryum glaucum* (Hedw.) Ångstr., *Polytrichum formosum* Hedw., and *Sphagnum* sp.

Sedge Meadow

This community is common in the WSPNP, one being more than 3 ha in size and located in the west-central part of the Preserve (41.27496°N, -88.16402°W). This sedge meadow was dominated by *Carex haydenii* (Hayden's sedge), and probably *C. stricta* (tussock sedge), with a combined I.V. of 29.3 and a mean cover of 27.12%. The few flowering stems found were all identified to *C. haydenii* though both species were probably present.

These two sedges are difficult to separate using vegetative material, and both formed hummocks on which many of the other species grow. *Onoclea sensibilis* was second in importance with an I.V. of 24.6 followed by *Thelypteris palustris* and *Calamagrostis canadensis*. Of the 36 species encountered in the plots, one was an exotic.

Shrub Swamp

A 3 ha shrub swamp was located at the northwest corner of the Preserve (41.21844°N, -88.16479°W). This swamp was dominated almost exclusively by *Cephalanthus occidentalis* (buttonbush) shrubs to 4 m tall that formed a nearly impenetrable thicket. Scattered throughout this thicket were a few trees of *Acer saccharinum* (silver maple), *Salix nigra* (black willow), *S. interior* (sandbar willow), and *Fraxinus lanceolata* (green ash). Buttonbush density averaged 12,400 small individuals (2 m tall) near the margin of the swamp to 8,600 larger individuals (4 m tall) in more mature areas near the middle and the eastern edge of the swamp. Here some individuals exceeded 12 cm dbh. *Bidens frondosa* (common beggar-tick) was the only ground layer species commonly encountered while *Lemna minor* (duckweed) floated on the water surface and on the sandy muck.

DISCUSSION

Dry to dry-mesic "black soil" prairies are relatively common in northern Illinois. This community, as described by White and Madany (1978), is dominated by *Schizachyrium scoparium* along with similar to smaller amounts of *Sorghastrum nutans* and *Heterostipa spartea* (Porcupine grass), a species not observed in our plots but observed on the prairies. In contrast, White and Madany (1978) mention that mesic prairies are dominated by *Andropogon gerardii* and *Sorghastrum nutans*. All three grasses were found on both of the dry to dry mesic prairies examined. *Schizachyrium scoparium* was the most important grass encountered and was well distributed throughout the prairies, occurring in nearly all plots. *Sorghastrum nutans*, in contrast, had a lower frequency and importance, while *Andropogon gerardi* was uncommon (Table 1). These three grass species were well distributed throughout the prairies, not being clumped and restricted to certain areas, an indication that the community was probably a little drier than typical dry-mesic prairies. The forbs encountered on both prairies were typical of those associated with dry-mesic prairies, and the large number of species encountered in the plots was typical of dry-mesic sites. The few exotic species present and the high species diversity indicated that the prairies were of high natural quality. Management should consist of occasional burns and the removal of trees and forest shrubs by cutting and the use of herbicides.

The two shrub prairies surveyed are the only shrub prairies that the authors have seen during their surveys of the Illinois glacial sand deposits during the past 12 years. Small disturbed remnants of this community type were seen at the Iroquois County Conservation Area, but these lacked many of the species encountered during the present study. This is one of the rarest community types in Illinois and management activities are undoubtedly necessary for maintenance. Burning and/or cutting and herbicide will be required to prevent the encroachment of tree species, but we know of no studies concerning management of this community type. In contrast, the sedge meadow communities are common in all glacial sand deposits in northern Illinois. Many similar examples are known from other sites in Will County, particularly Braidwood Dunes and Savanna Nature Preserve (Phillippe et al. 2008), Hitts Siding Prairie Nature Preserve (Marcum et

al. 2011), and Sand Ridge Savanna Nature Preserve (Phillippe et al. 2011). All are similar in structure and floristic composition.

Presently, we have been unable to find any published literature concerning the species composition and structure of buttonbush shrub swamps other than general information from some site evaluations. Most of this information is from materials in the files of the original Illinois Natural Areas Inventory of the late 1970s (White 1978). White and Madany (1978) recognized this community with at least 50% coverage by shrubs, and less than 20% coverage by trees. A community with less than 50% shrub cover was considered a pond, while a community with more than 20% tree cover would be classified as a swamp. Most important consideration in preserving this community type in sand areas is maintaining a high water table for most of the year.

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Table 1. Frequency (%), mean cover (% of total area), and importance value (I.V.) for species encountered in two dry to dry-mesic "black soil" prairies on sandy loam soil at Wilmington Shrub Prairie Nature Preserve, Will County, Illinois. Species with I.V. <2.4 are listed as others. (*exotics)

Species	South Central Prairie			North Edge Prairie		
	Freq. %	Mean Cover	I.V.	Freq. %	Mean Cover	I.V.
Helianthus mollis	100	21.93	17.6	98	13.02	15.5
Parthenium integrifolium	100	19.71	16.1	100	19.71	20.9
Schizachyrium scoparium	94	15.78	13.4	100	19.50	20.8
Solidago missouriensis	100	14.22	12.6	6	0.42	0.6
Rubus flagellaris	62	13.02	10.5	60	4.43	6.7
Euthamia gymnospermoides	98	9.84	9.8	92	6.11	9.7
Potentilla simplex	100	8.80	9.1	36	1.12	2.8
Sorghastrum nutans	88	6.04	6.9	82	9.66	12.0
**Poa pratensis*	82	3.31	4.9	100	3.67	8.2
Aletris farinosa	56	4.13	4.6	--	--	--
Phlox glaberrima	100	1.45	4.3	92	2.00	6.5
Scleria triglomerata	94	1.67	4.3	30	1.28	2.6
Coreopsis tripteris	88	1.64	4.1	90	5.96	9.4
Euphorbia corollata	86	1.13	3.7	42	0.71	2.8
Antennaria plantaginifolia	58	2.54	3.6	--	--	--
Spiraea tomentosa	48	3.12	3.6	--	--	--
Viola sagittata	88	0.54	3.4	100	2.73	7.5
**Achillea millefolium*	72	1.26	3.3	94	1.57	6.3
Juncus greenei	86	0.43	3.3	20	0.15	1.2
Hieracium canadense	74	0.92	3.1	--	--	--
Liatris pycnostachya	82	0.46	3.1	--	--	--
**Rumex acetosella*	74	0.97	3.1	28	1.26	2.5
Comandra umbellata	70	0.60	2.8	--	--	--
Krigia biflora	60	0.75	2.6	--	--	--
Lespedeza capitata	52	1.01	2.5	36	1.07	2.7
Thelypteris palustris	14	3.00	2.4	--	--	--
Solidago nemoralis	46	1.07	2.3	38	1.76	3.4
Cornus racemosa	32	1.72	2.2	88	9.36	12.0
Dichanthelium acuminatum	54	0.32	2.1	40	0.35	2.4
Andropogon gerardii	16	0.13	0.6	36	2.76	4.1
Solidago altissima	6	0.66	0.6	20	1.80	2.5
Eryngium yuccifolium	--	--	--	92	7.65	11.0
Carex umbellata	--	--	--	88	2.57	6.7
Liatris spicata	--	--	--	36	0.63	2.4
Others	--	12.81	33.5	--	5.00	16.8
Totals		154.98	200.0		126.25	200.0
Bare ground and litter		17.58			19.65	

Table 2. Frequency (%), mean cover (% of total area), and importance value (I.V.) for the species encountered in two shrub prairies at Wilmington Shrub Prairie Nature Preserve, Will County, Illinois. Species with I.V. <1.6 are listed as others. (*exotics)

Species	West Shrub Prairie			East Shrub Prairie		
	Freq. %	Mean Cover	I.V.	Freq. %	Mean Cover	I.V.
Spiraea tomentosa	100	31.80	32.3	64	11.24	12.9
Rubus hispidus	100	19.02	22.7	96	26.20	25.9
Onoclea sensibilis	96	13.34	18.0	76	11.40	14.0
Osmunda regalis	52	14.20	15.0	60	16.34	16.2
Solidago altissima	84	10.10	14.6	8	0.14	0.7
Carex longii	72	4.94	9.7	28	1.50	3.3
Juncus dudleyi	72	3.38	8.5	12	0.06	1.0
Solidago gigantea	56	4.54	8.1	4	0.12	0.4
Eleocharis verrucosa	56	4.16	7.8	36	0.18	3.0
Liatris spicata	56	3.40	7.2	--	--	--
Viola lanceolata	64	2.36	7.0	36	0.38	3.2
Euthamia gymnospermoides	44	3.52	6.3	24	1.10	2.7
Agrimonia parviflora	40	2.34	5.1	8	0.14	0.7
Scirpus cyperinus	28	3.72	5.1	4	0.02	0.3
Dichanthelium acuminatum	40	0.30	3.5	24	0.12	2.0
Vernonia missurica	16	2.40	3.1	32	2.30	4.2
Bryophytes	32	0.46	2.9	80	22.38	22.0
Andropogon virginicus	16	1.44	2.4	--	--	--
Ambrosia artemisiifolia	20	0.10	1.7	--	--	--
Coreopsis tripteris	8	1.20	1.6	--	--	--
Salix humilis	8	1.20	1.6	--	--	--
Bartonia virginica	4	0.02	0.3	28	0.14	2.3
Cornus obliqua	4	0.02	0.3	16	1.82	2.6
Aronia melanocarpa	--	--	--	76	20.50	20.4
Andropogon gerardii	--	--	--	64	4.98	8.6
Carex haydenii/stricta	--	--	--	56	4.16	7.7
Carex pensylvanica	--	--	--	32	3.68	5.2
Spiraea alba	--	--	--	24	4.02	4.7
Lycopus uniflorus	--	--	--	48	0.74	4.3
Aster lanceolatus	--	--	--	40	1.18	4.0
Persicaria amphibium	--	--	--	40	1.08	4.0
Thelypteris palustris	--	--	--	20	2.04	3.0
Carex vulpinoidea	--	--	--	12	1.80	2.3
Carex scoparia	--	--	--	16	0.86	1.9
**Poa pratensis*	--	--	--	16	0.76	1.8
Lysimachia terrestris	--	--	--	16	0.48	1.6
Others	--	3.62	15.2	--	1.78	13.1
Totals		131.58	200.0		143.64	200.0
Bare ground and litter		9.52			3.48	

Table 3. Frequency (%), mean cover (% of total area), relative frequency, relative cover, and importance value (I.V.) for the ground layer species encountered in a sedge meadow at Wilmington Shrub Prairie Nature Preserve, Will County, Illinois. (*exotics)

Species	Freq. %	Mean Cover	Rel. Freq.	Rel. Cover	I. V.
Carex haydenii/stricta	100	27.12	7.9	21.4	29.3
Onoclea sensibilis	100	21.02	7.9	16.7	24.6
Thelypteris palustris	92	13.80	7.2	11.0	18.2
Calamagrostis canadensis	100	12.24	7.9	9.7	17.6
Agrimonia parviflora	92	11.90	7.2	9.5	16.7
Solidago gigantea	76	9.76	6.0	7.8	13.8
Aster praealtus	72	8.88	5.6	7.1	12.7
Hypericum sphaerocarpum	96	5.36	7.5	4.3	11.8
Pycnanthemum virgnianum	68	1.34	5.3	1.0	6.3
Lycopus uniflorus	64	1.20	5.0	1.0	6.0
Galium obtusum	68	0.34	5.3	0.3	5.6
Spiraea alba	28	3.62	2.2	2.9	5.1
Lathyrus palustris	56	0.38	4.4	0.3	4.7
Helianthus grosseserratus	20	3.00	1.6	2.4	4.0
Persicaria amphibium	36	0.48	2.8	0.4	3.2
Boehmeria cylindrica	24	1.38	1.9	1.0	2.9
Lycopus americanus	32	0.36	2.5	0.3	2.8
Euthamia graminifolia	24	0.62	1.9	0.5	2.4
Solidago altissima	12	0.84	0.9	0.7	1.6
Bidens polylepis	16	0.28	1.2	0.2	1.4
Stachys pilosa	16	0.08	1.2	0.1	1.3
Ulmus americana	8	0.62	0.6	0.5	1.1
Eleocharis palustris	12	0.16	0.9	0.1	1.0
Muhlenbergia mexicana	8	0.24	0.6	0.2	0.8
Epilobium leptophyllum	8	0.14	0.6	0.1	0.7
Verbena hastata	8	0.14	0.6	0.1	0.7
Caltha palustris	8	0.04	0.6	--	0.6
Apocynum cannabinum	4	0.12	0.3	0.1	0.4
Cornus obliqua	4	0.12	0.3	0.1	0.4
Rubus allegheniensis	4	0.12	0.3	0.1	0.4
Scrirpis cyperinus	4	0.12	0.3	0.1	0.4
Acer saccharinum	4	0.02	0.3	--	0.3
Epilobium coloratum	4	0.02	0.3	--	0.3
Geum laciniatum	4	0.02	0.3	--	0.3
Liparis loeselii	4	0.02	0.3	--	0.3
**Poa pratensis*	4	0.02	0.3	--	0.3
Totals		125.92	100.0	100.0	200.0
Bare ground and litter		5.50			

Table 4. Plant density (#/ha) and stem density by basal diameter in diameter classes of *Cephalanthus occidentalis* in three vegetation zones of a buttonbush shrub swamp at Wilmington Shrub Prairie Nature Preserve, Will County, Illinois.

Vegetation Zones	Total Shrubs (#ha)	Stems by Basal Diameter Classes (#/ha) 1.0-≤2.5 cm	>2.5-5.0 cm	>5.1+ cm	Total Stems
Swamp Margin Totals	12400	17000	7000	--	24000
Mature Swamp Totals	10400	10000	23000	7200	40200
Old-age Swamp Totals	8600	8600	10000	8000	26600

APPENDIX 1

Vascular plant species encountered at Wilmington Shrub Prairie Nature Preserve, Will County, Illinois, are listed alphabetically by family under major plant groups. Collecting numbers preceded by a P were collected by Loy R. Phillippe. All specimens are deposited in the Illinois Natural History Survey Herbarium, Champaign, Illinois (ILLS). (*exotic species)

FERN AND FERN-ALLIES
Aspleniaceae
Asplenium platyneuron (L.) Oakes: P41187

Equisetaceae
Equisetum arvense L.: P41205
Equisetum fluviatile L.: P40104
Equisetum hyemale L.: P40315

Onocleaceae
Onoclea sensibilis L.: P39779

Ophioglossaceae
Botrychium virginianum (L.) Sw.: P41766
Ophioglossum vulgatum L.: P39778

Osmundaceae
Osmunda cinnamomea L.: P40045
Osmunda regalis L.: P39759

Thelypteridaceae
Thelypteris palustris Schott: P40319

GYMNOSPERMS
Cupressaceae
Juniperus virginiana L.:P42136

MONOCOTS
Alismataceae
Alisma subcordatum Raf.: P40108
Sagittaria brevirostrata Mack. & Bush: P42169
Sagittaria cuneata Sheld.: P40105

Amaryllidaceae
Hypoxis hirsuta (L.) Coville: P39457

Araceae
Arisaema dracontium (L.) Schott: P40326

Commelinaceae
**Commelina communis* L.: P42146
Tradescantia ohiensis Raf.: P39780

Cyperaceae
Bulboschoenus fluviatilis (Torr.) Sojak.: P42161
Carex bicknellii Britt.: P41837
Carex brachyglossa Mack.: P41796
Carex buxbaumii Wahlenb.: P40911
Carex cephalophora Muhl.: P41783
Carex conoidea Schk.: P39462
Carex cristatella Britt.: P40320
Carex haydenii Dewey: observed
Carex longii Mack.: P40210
Carex pellita Willd.: P39768
Carex pensylvanica Lam.: observed
Carex sartwellii Dewey: P41793
Carex scoparia Schk.: P39769
Carex stricta Lam.: observed
Carex swanii (Fern.) Mack.: P39819
Carex umbellata Schk.: P39461
Carex vulpinoidea Michx.: P41794
Cyperus erythrorhizos Muhl.: P40110
Cyperus esculentus L.: P40109
Cyperus strigosus L.: P42150
Eleocharis ovata (Roth) Roem. & Schultes var. *obtusa* (Willd.) Kukenth: P41801
Eleocharis palustris (L.) Roem. & Schultes: P39767
Eleocharis verrucosa (Svenson) Harms: P41836
Eleocharis wolfii Gray: P41799
Rhynchospora capitellata (Mixhx.) Vahl: P42122
Scirpus atrovirens Willd.: P40086
Scirpus cyperinus (L.) Kunth: P39770
Scirpus pendulus Muhl.: P39815
Scleria triglomerata Michx.: P39812

Iridaceae
Iris shrevei Small: P39766
Sisyrinchium albidum Raf.: P39468

Juncaceae
Juncus acuminatus Michx.: P39784
Juncus anthelatus (Wieg.) R.E. Brooks: P41774
Juncus brachycarpus Engelm.: P41782
Juncus dudleyi Wieg.: P39822
Juncus effusus L.: P39756
Juncus greenei Oakes & Tuckerm.: P40124
Juncus interior Wieg.: P41842
Juncus marginatus Rostk.: P40815
Juncus tenuis Willd.: P39776
Juncus torreyi Coville: P40306

Liliaceae
Aletris farinosa L.: P40298
**Asparagus officinalis* L.: P40313

Lilium michiganense Farw.: P40816
Smilacina racemosa (L.) Desf.: P40097

Orchidaceae
Goodyera pubescens (Willd.) R. Br.: P40812
Liparis loeselii (L.) Rich.: P40112
Platanthera clavellata (Michx.) Luer: P40814
Platanthera lacera (Michx.) G. Don: P41807
Spiranthes cernua (L.) Rich.: P42149
Spiranthes magnicamporum Sheviak: P42171

Poaceae
Agrostis gigantea Roth: P39762
Agrostis hyemalis (Walt.) BSP.: P39793
Agrostis perennans (Walt.) Tuckerm.: P40100
Andropogon gerardii Vitman: P40073
Andropogon virginicus L.: P40329
Aristida basiramea Engelm.: P42137
Aristida purpurascens Poir.: P40297
Aristida oligantha Michx.: P42138
**Bromus inermis* Leyss.: P41791
Calamagrostis canadensis (Michx.) P. Beauv.: P39755
Cenchrus longispinus (Hack.) Fern.: P42155
Cinna arundinacea L.: P40102
Dichanthelium acuminatum (Sw.) Gould & Clark: P39820
Dichanthelium clandestinum (L.) Gould: P39777
**Digitaris ischaemum* (Schreb.) Schreb.: P42157
**Digitaria sanguinalis* (L.) Scop.: P42144
**Echinochloa crus-galli* (L.) P. Beauv.: P40106
Elymus canadensis L.: P40066
Elymus virginicus L.: P40111
**Elytrigia repens* (L.) Desv.: P41800
Eragrostis frankii C.A. Meyer: P40128
Festuca subverticillata (Pers.) E.B. Alexeev.: P41765
Glyceria striata (Lam.) Hitchc.: P39794
Heterostipa spartea (Trin.) Barkworth: P39807
Koeleria macrantha (Ledeb.) Spreng.: P39811
Leersia oryzoides (L.) Swartz: P41191
Leersia virginica Willd.: P40325
Muhlenbergia mexicana (L.) Trin.: P40042
Muhlenbergia schreberi J.F. Gmel.: P42165
Panicum capillare L.: P40136
Panicum dichotomiflorum Michx.: P42143
Panicum rigidulum Bosc.: P41193
Panicum virgatum L.: P40077
**Phalaris arundinacea* L.: P41792
**Phragmites australis* (Cav.) Trin.: P40322
**Poa compressa* L.: P41838
**Poa pratensis* L.: P39475
Schizachyrium scoparium (Michx.) Nash: P40119
**Setaria faberi* R.A.W. Herrm.: P40135
Setaria glauca (L.) P. Beauv.: P42158
Sorghastrum nutans (L.) Nash: P40120
Spartina pectinata Link: P41208
Sphenopholis intermedia (Rydb.) Rydb.: P39801
Vulpia octoflora (Walt.) Rydb.: P41785

Smilacaceae
Smilax tamnoides L.: P42147

Typhaceae
Typha latifolia L.: P39771

DICOTS
Acanthaceae
Ruellia humilis Nutt.: P39816

Aceraceae
Acer negundo L.: P42163
Acer saccharinum L.: P39482

Anacardiaceae
Rhus glabra L.: P40138
Toxicodendron radicans (L.) Kuntze: P41203

Apiaceae
Cicuta maculata L.: P39763
Cryptotaenia canadensis (L.) DC.: P40061
Eryngium yuccifolium Michx.: P41188
Oxypolis rigidior (L.) Raf.: P40053
Sanicula canadensis L.: P41763
Sanicula odorata (Raf.) Pryer & Phillippe: P41786
Sium suave Walt.: P40113
Zizia aurea (L.) Koch: P41840

Apocynaceae
Apocynum cannabinum L.: P41805

Asclepiadaceae
Asclepias hirtella (Pennell) Woodson: P40122
Asclepias incarnata L.: P39764
Asclepias sullivantii Engelm.: P40317

Asteraceae
**Achillea millefolium* L.: P39824
Ageratina altissima (L.) R.M. King & H. Robins.: P42115
Ambrosia artenisiifolia L.: P40099
Ambrosia trifida L.: P42147a
Antennaria neglecta Greene: P41835
Antennaria plantaginifolia (L.) Hook.: P39473
**Arctium minus* L.: P42180
Arnoglossum plantagineum Raf.: P39805
Aster dumosus L.: P40115, P40211
Aster ericoides L.: P40310
Aster lanceolatus Willd.: P42175
Aster novae-angliae L.: P40304
Aster ontarionis Wieg.: P40303

Aster pilosus Willd.: P40295
Aster praealtus Poir.: P40081
Aster puniceus L.: P40307
Bidens aristosa (Michx.) Britt.: P42121
Bidens comosa (Gray) Wieg.: P40318
Bidens frondosa L.: P42173
Bidens polylepis Blake: P42129
Cirsium discolor (Muhl.) Spreng.: P40046
**Cirsium vulgare* (Savi) Tenore: P40137
Conyza canadensis (L.) Cronq.: P42156
Coreopsis tripteris L.: P40065
Erechtites hieracifolia (L.) Raf.: P40085
Erigeron annuus (L.) Pers.: P41773
Erigeron strigosus Muhl.: P41844
Eupatoriadelphus maculatus (L.) R.M. King & H. Rob.: P40084
Eupatorium altissimum L.: P40311
Eupatorium perfoliatum L.: P40038
Eupatorium serotinum Michx.: P40131
Euthamia graminifolia (L.) Nutt.: P40090
Euthamia gymnospermoides Greene: P40213
Helenium autumnale L.:P42166
Helianthus grosseserratus Maretns: P40076
Helianthus mollis Lam.: P40093
Helianthus tuberosus L.: P42154
Heliopsis helianthoides (L.) Sweet: P40139
Hieracium canadense Michx.: P42128
Hieracium gronovii L.: P40096
Krigia biflora (Walt.) Blake: P41779
Lactuca biennis (Moench) Fern.: P40067
Lactuca canadensis L.: P40121
Lactuca floridana (L.) Gaertn.: P42147b
Liatris pycnostachya Michx.: P41834
Liatris spicata (L.) Willd.: P40071, P40082
Oligoneuron riddellii (Frank) Rydb.: P40308
Parthenium integrifolium L.: 39810
Prenanthes racemosa Michx.: P40302
Pseudognaphalium obtusifolium (L.) Hilliard & Burtt.: P40292
Ratibida pinnata (Vent.) Barnh.: P39818
Rudbeckia hirta L.: P39806
Rudbeckia laciniata L.: P40047
Rudbeckia subtomentosa Pursh: P40055
Rudbeckia sullivantii Boynt. & Beadle: P40129
Silphium integrifolium Michx.: P40064
Silphium laciniatum L.: P40314
Silphium terebinthinaceum Jacq.: P40059
Solidago altissima L.: P40216
Solidago gigantea Ait.: P40057
Solidago missouriensis Nutt.: P40117
Solidago nemoralis Ait.: P40214
Solidago speciosa Nutt.: P40215
Vernonia fasciculata Michx.: P40114
Vernonia missurica Raf.: P40054

Balsaminaceae
Impatiens capensis Meerb.: P40083

Boraginaceae
Hackelia virginiana (L.) I.M.Johnston: P42116
Lithospermum canescens (Michx.) Lehm.: P39467

Brassicaceae
**Alliaria petiolata* (Bierb.) Cavara & Grande: P39456
Arabis shortii (Fern.) Gl.: P39455
Cardamine bulbosa (Muhl.) BSP.: P39477

Caesalpiniaceae
Chamaecrista fasciculata (Michx.) Greene: P40293
Gleditsia triacanthos L.: P41788

Campanulaceae
Campanula aparinoides Pursh: P39796
Campanulastrum americanum (L.) Small: P40051
Lobelia cardinalis L.: P40092
Lobelia siphilitica L.: P40324
Lobelia spicata Lam.: P40134

Caprifoliaceae
**Lonicera x bella* Zabel: P39799
Sambucus canadensis L.: P39782
Viburnum lentago L.: P39775
Viburnum opulus L.: P42177
Viburnum prunifolium L.: P39478

Caryophyllaceae
**Stellaria media* (L.) Cyrillo: P39480

Chenopodiaceae
**Chenopodium album* L.: P41197

Convolvulaceae
Calystegia sepium (L.) R. Br.: P41798

Cornaceae
Cornus obliqua Raf.: P39758
Cornus racemosa Lam.: P40050

Corylaceae
Corylus americana Walt.: P40101

Cuscutaceae
Cuscuta coryli Engelm.: P40068:

Elaeagnaceae
**Elaeagnus umbellata* Thunb.: P39465

Ericaceae
Vaccinium angustifolium Ait.: P39472

Euphorbiaceae
Acalypha rhomboidea Raf.: P40098

Euphorbia corollata L.: P39813

Fabaceae
Amorpha canescens Pursh: P39808
Dalea purpurea Vent.: P39814
Desmodium canadense (L.) DC.: P40123
Lathyrus palustris L.: P39765, P40079
Lespedeza capitata Michx.: P40116
Lespedeza virginica ((L.) Britt.: P41832
**Lotus corniculatus* L.: P39821
Strophostyles helvula (L.) Ell.: P41195

Fagaceae
Quercus velutina Lam.: P40328

Gentianaceae
Bartonia virginica (L.) BSP.: P40209
Gentiana saponaria L.: P40296

Grossulariaceae
Ribes missouriense Nutt.: P42181

Haloragidaceae
Proserpinaca palustris L.: P39788

Hypericaceae
Hypericum majus (Gray) Britt.: P41189
Hypericum sphaerocarpum Michx.: P39774
Triadenum fraseri (Spach) Gl.: P40088

Lamiaceae
Lycopus americanus Muhl.: P40062
Lycopus uniflorus Michx.: P40103
Lycopus virginicus L.: P42167
Monarda fistulosa L.: P41207
Physostegia virginiana (L.) Benth.: P40078
Prunella vulgaris L. var. *elongata* Benth.: P40305
Pycnanthemum virginianum (L.) Dur. & B.D. Jacks.: P40074
Scutellaria lateriflora L.: P40041
Stachys pilosa Nutt.: P39773
Teucrium canadense L.:P41804

Lauraceae
Sassafras albidum (Nutt.) Nees: P39464

Linaceae
Linum medium (Planch.) Britt.: P40813

Lythraceae
Lythrum alatum Pursh: P39792

Menispermaceae
Menispermum canadense L.: P40303.1

Mimosaceae
Desmanthus illinoensis (Michx.) MacM.: P40132

Molluginaceae
**Mollugo verticillata* L.: P42148

Moraceae
**Maclura pomifera* (Raf.) Schneider: P42170
**Morus alba* L.: P41803

Nyssaceae
Nyssa sylvatica Marsh.: P39761

Oleaceae
Fraxinus lanceolata Borkh.: P41802

Onagraceae
Circaea lutetiana L.: P39800
Epilobium coloratum Biehler: P40044
Epilobium leptophyllum Raf.: P42118
Ludwigia alternifolia L.: P40089
Ludwigia palustris (L.) Ell.: P39790
Ludwigia polycarpa Short & Peter: P39789
Oenothera laciniata Hill: P42142
Oenothera pilosella Raf.: P39772

Oxalidaceae
Oxalis violacea L.: P39459

Phrymaceae
Phryma leptostachya L.: P40056

Phytolaccaceae
Phytolacca americana L.: P41764

Plantaginaceae
Plantago rugelii Decne: P40309

Polemoniaceae
Phlox glaberrima L.: P39757
Polemonium reptans L.: P39476

Polygalaceae
Polygala cruciata L.: P41199
Polygala sanguinea L.: P40118

Polygonaceae
Antenoron virginianum (L.) Roberty & Vautier: P40060
Fallopia scandens (L.) Holub: P40069
Persicaria amphibium (L.) S.F. Gray: P42122
Persicaria coccinea (Muhl.) Greene: P42141
Persicaria hydropiperoides (Michx.) Small: P41202
Persicaria opelousana (Riddell) Small: P42125
Persicaria pensylvanica (L.) Small: P40141
Persicaria punctata (Ell.) Small: P40058
**Rumex acetosella* L.: P39823

Portulacaceae
Claytonia virginica L.: P39458

Primulaceae
Lysimachia lanceolata Walt.: P40212
Lysimachia quadriflora Sims.: P39817
Lysimachia terrestris (L.) BSP.: P39760

Ranunculaceae
Caltha palustris L.: P39483
Ranunculus abortivus L.: P39479
Thalictrum dasycarpum Fisch. & Lall.: P39802

Rhamnaceae
**Frangula alnus* Mill.: P39798
**Rhamnus cathartica* L.: P41806

Rosaceae
Agrimonia parviflora Sol.: P40063
Aronia melanocarpa (Michx.) Ell.: P39463
Fragaria virginiana Duchesne: P39470
Geum canadense Jacq.: P39795
Geum laciniatum Murr.: P39804
Malus ioensis (Wood) Britt.: P39481
**Malus pumila* Mill.: P39466
**Potentilla norvegica* L.: P41787
Potentilla simplex Michx.: P41198
Prunus serotina Ehrh.: P40142
Rosa carolina L.: P42176
**Rosa multifolia* Thunb.: P42117
Rosa palustris Marsh.: P39754
Rubus allegheniensis Porter: P41843
Rubus flagellaris Willd.: P41841
Rubus hispidus L.: P41780
Rubus occidentalis L.: P41767
Spiraea alba DuRoi: P39781
Spiraea tomentosa L.: P40094

Rubiaceae
Cephalanthus occidentalis L.: P39785
Galium obtusum Bigel.: P41204
Galium triflorum Michx.: P40301

Salicaceae
Populus deltoids Marsh.: P41790
Populus tremuloides Michx.: P41797
Salix discolor Muhl.: P41769
Salix humilis L.: P42151
Salix interior Rowlee: P42168
Salix nigra Marsh.: P41789

Santalaceae
Comandra umbellata (L.) Nutt.: P41196

Saxifragaceae
Penthorum sedoides L.: P40125

Scrophulariaceae
Agalinis purpurea (L.) Pennell: P40291
Agalinis tenuifolia (Vahl) Raf.: P40127
Castilleja coccinea (L.) Spreng.: P41778
Chelone glabra L.: P41200
Leucospora multifida (Michx.) Nutt.: P40126
Lindernia dubia (L.) Pennell: P39786
Mimulus alatus Sol.: P40040
Pedicularis canadensis L.: P39809
Pedicularis lanceolata Michx.: P40070
Penstemon digitalis Nutt.: P40133
Scrophularia lanceolata Pursh: P41194
Veronicastrum virginicum (L.) Farw.: P39803

Solanaceae
Solanum carolinense L.: P42145
**Solanum dulcamara* L.: P39783
**Solanum dulcamara* L. f. *albiflorum* House: P39797
Solanum ptychanthum Duanl: P40095

Ulmaceae
Celtis occidentalis L.:P42179
Ulmus americana L.: P40327

Urticaceae
Boehmeria cylindrica (L.) Sw.: P40039
Laportea canadensis (L.) Wedd.: P42164
Parietaria pensylvanica Muhl.: P41762
Pilea fontana (Lunell) Rydb.: P40321
Pilea pumila (L.) Gray: P40300
Urtica gracilis Ait.: P41209

Verbenaceae
Phyla lanceolata (Michx.) Greene: P40107
Verbena hastata L.: P39791
Verbena urticifolia L.: P40048

Violaceae
Viola lanceolata L.: P39471
Viola pratincola Greene: P39469
Viola sagittata Ait.: P39460, P39474

Vitaceae
Parthenocissus quinquefolia (L.) Planch.: P40043
Vitis riparia Michx.: P40087

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September 2008 Heavy Rains in Northeast Illinois: Meteorological Analysis and Impacts

Victor Gensini[1], Alan Black [2], David Changnon [1], Stanley Changnon [2]
[1] Meteorology Program, Department of Geography
Northern Illinois University; DeKalb, Illinois
[2] Illinois State Water Survey, Institute of Natural Resource Sustainability
University of Illinois; Champaign, Illinois

Corresponding Author: David Changnon
#118 Davis Hall, Meteorology Program, Department of Geography,
Northern Illinois University, DeKalb, Illinois 60115; Email: dchangnon@niu.edu

ABSTRACT

During 12-14 September 2008, an unlikely combination of abundant atmospheric moisture associated with the remnants of two tropical storms (Lowell from the Pacific Ocean and Ike from the Gulf of Mexico) and frontal lifting associated with a slow-moving cold front draped across the upper Mississippi River valley, produced record rainfall over parts of northern Illinois. Chicago's O'Hare airport set its all-time 24-h (midnight to midnight) rainfall record with 6.64 in. on 13 September. The heavy rains created historical flooding along most rivers in northern Illinois and northwestern Indiana, closed regional interstates, cancelled flights out of Chicago's Midway and O'Hare airports, placed many corn and soybean crops under water, and were linked to four deaths in the metropolitan area. A meso-/synoptic-scale analysis of the three-day period identified that heavy rains occurred over similar locations for extended periods. The unusual aspect of this event was the record-breaking 24-h precipitation totals in the absence of thunderstorm activity.

INTRODUCTION

Over the weekend of 12-14 September 2008, clouds above northern Illinois unleashed record rainfalls in what appears to be another case of a meteorological "perfect storm." This near-continuous rainfall quickly saturated soils leading to widespread flooding of creeks and rivers. By the morning of the 14th, Chicago's Deep Tunnel was completely full and the city was forced to release 90 billion gallons of storm runoff and untreated sewer water into Lake Michigan. Automobile, train, and aircraft traffic were severely restricted, isolating many of the Chicago metropolitan area's eight million residents.

Why was this event so unusual and worth further investigation? Heavy rainstorms causing two inches or more occur about once a year in Chicago (Huff and Angel 1989). When storms of this magnitude occur frequently over a couple of months they can lead to widespread impacts in the Chicago metropolitan region (Changnon and Westcott 2002).

Recent events (e.g., summer 1993 and July 1996) that produced significantly higher point rainfall totals in this region have created extreme social and economic impacts (Kunkel 1996; Changnon 1999; Changnon and Kunkel 1999). Most heavy rainstorms that occur in the upper Midwest are associated with thunderstorms (i.e., deep convection) that develop along a stationary or slow-moving frontal boundary (Huff 1978; Huff 1979; Changnon and Huff 1980; Kunkel 1996; Changnon and Kunkel 1999; Hilberg 2003). Climate records indicate that Chicago's Midway airport (a longer standing record than O'Hare) had only four previous cases of two consecutive days with ≥ 2-in precipitation totals in a 24-h period (midnight to midnight). Further analyses indicated that three of the four were associated with training thunderstorm clusters along an east-west quasi-stationary boundary draped across northern Illinois. Interestingly, this event was not associated with thunderstorms producing a range of hazardous weather, and, most who experienced this event never heard thunder. Instead, the event was characterized by an unusually long and continuous period when deep tropical moisture streamed into the region and was lifted by a slow-moving cold front. Analysis of the historical fourth case depicted analogous spatial and temporal meteorological features to those found during this event. Had this "perfect storm" occurred before? This paper investigates the meso- and synoptic-scale features present during this 72-h period, including a comparison to a similar historical occurrence, the related hydro-climatic elements of the event, and numerous impacts across the region.

DATA AND APPROACH

The meteorological analysis of the 12-14 September 2008 event examined a number of archived variables including those found in local and regional surface and upper-air analyses, and modeled historical data from the North American Regional Reanalysis (NARR). The NARR provides researchers with a consistent climate data suite for North America (Mesinger et al. 2006). The regional reanalysis is produced at high spatial and temporal resolutions (32-km, 45-layer, 3-hourly) and provides records from 1979 to present. NARR data were joined with National Weather Service (NWS) surface and upper-air data to construct spatio-temporal characteristics of the event, highlighting unusual features of the 72-hour duration storm.

Surface point rainfall totals from the NWS and the CoCoRaHs (Cifelli et. al 2005) network were used to plot daily and event rainfall totals in a geographic information system (GIS). Hourly METAR data were also examined to identify periods when precipitation may have been convective in nature (e.g., lightning in the METAR observations implies that thunderstorms were dominant around the time of the observation). Additionally, hydrographs and peak discharge values were examined in a GIS from various rivers to relate these values to impacts that occurred across Northeast Illinois.

RESULTS

Meso-/Synoptic Scale Analysis

An ingredients-based forecast approach (Doswell et al. 1996) utilized by Junker et al. (1999) showed that precipitable water (PW) anomalies were an important characteristic in identifying heavy rainfall events during the great Midwest floods of 1993 (e.g., the majority of heavy rain events were associated with PW values greater than an inch above

the norm). A rich feed of tropical moisture was already in the region around 0000 UTC on the 12th, as noted by a ridge of high surface dewpoints (≥ 65 °F) streaming as far north as southeastern Minnesota (Fig. 1). Deep-tropical moisture associated with remnants of a tropical system in the Eastern Pacific (Lowell) began streaming in from the southwest on the morning of the 12th. PW values had already started approaching 1.5 in., which was about 150 % of normal (Tuller 1968). Figure 2 shows a PW time-series of the event, as depicted from the two closest upper-air observation sites Davenport, IA (KDVN) and Lincoln, IL (KILX). Remarkably, PW values at KILX were able to persist above 2 in. for 60 hours! This was primarily due to the lack of forcing for the movement of the cold front with unidirectional vertical wind profiles aligning parallel to the surface cold front. This allowed for showers and a few thunderstorms to train along the same terrain for multiple days. Figure 3 shows slow progression of the surface cold front across the region for a 48-h period from 1200 UTC 12 September to 1200 UTC 14 September 2008. It appears that during a 24-h period from 1200 UTC 12 September to 1200 UTC 13 September, the cold front was more or less a stationary air mass boundary. However, the authors decided to demarcate this boundary on the surface maps as a cold front due to the nature of the front's progression during this period (e.g., the front traveled nearly 100 miles to the east during the day on the 12th and then was pushed westward with enhanced moisture associated with a nocturnal low-level jet stream during the early morning hours on the 13th). Secondly, a reinforcement of deep-tropical moisture related with remnants of Hurricane Ike from the Gulf of Mexico helped maintain a moist source region for the precipitation to draw on. The unidirectional nature of the vertical wind profile and deep tropical moisture associated with this event are revealed by atmospheric vertical profiles from KDVN and KILX (Fig. 4).

Many heavy rain events in northern Illinois are the result of thunderstorms. Another heavy rainfall event in northern Illinois on 17 July 1996 produced as much as 16 in. of rainfall in a 36-h period but was associated with intense convective activity (Changnon and Kunkel 1999). During that event, National Weather Service (NWS) WSR-88D radar near Chicago indicated reflectivities of 50 to 60 dBZ lasting for as long as 20 hours (Changnon and Kunkel 1999). In contrast, this event produced few reflectivities above 50 dBZ. Surface stations in northern Illinois reported thunder for a few hours, generally between 2200 LST 12 September and 0900 LST 13 September. Overall, METAR observations indicated that thunder was reported during only 10% to 20% of the event.

Hydro-Climatic Assessment

The rains of 12-14 September, 2008 were remarkable in terms of their hydro-climatic impacts across northern Illinois. A total of 87 daily precipitation records were set in Illinois during the three-day period. On 13 September, all-time daily precipitation records were set at Chicago O'Hare and at DuPage County Airport in West Chicago. Chicago O'Hare received 6.64 in. of rain (previous record 6.49 in.) while DuPage County Airport received 6.02 in. (previous record 3.47 in.). Elsewhere in Illinois, the cities of Keithsburg, Marietta, and Winchester also broke their all-time daily precipitation record on 13 or 14 September. Precipitation totals exceeded the 100-year return frequency across a 30-mile swath from Galesburg, IL northeast to northern Chicago (Fig.5). Precipitation totals for the event of greater than 10 inches were found across parts of DeKalb, Kane, DuPage and Cook counties in Illinois and Lake and Porter counties in Indiana (Figure 6).

Hourly rainfall data from Moline, IL and Chicago O'Hare were investigated to assess the temporal dimension of the event (Figure 7). Precipitation started around 1100 LST 12 September 2008 in western Illinois and continued for 33 continuous hours with no thunder reported in hourly observations. Heaviest amounts occurred during the late evening of 12 September and the early morning of 13 September, with 1.43 in. falling in the one-h period ending at 0000 LST 13 September 2008. At Chicago O'Hare, precipitation fell for 59 straight hours from approximately 0500 LST 12 September through 1500 LST 14 September 2008. Unlike the precipitation at Moline, thunder was reported during 2 of the 59 hours at Chicago O'Hare. While these two hours only account for 3% of the event, 2.25 inches of precipitation fell (about 26%) out of the 8.45 inches recorded by the hourly observations during the 59-h period. Again, the relative lack of thunder is remarkable given that most heavy precipitation events in the upper Midwest are associated with thunderstorms.

The extreme precipitation totals led to river flooding. Several rivers across the northern half of Illinois exceeding 100-year return interval streamflow (Figure 8). Rivers throughout northern Illinois rose rapidly on 13 and 14 September 2008 (Figure 9). In Wood Dale, IL, Salt Creek rose 8 feet in two days, from 7.36 feet on 12 September to 16.12 feet on 14 September. The Des Plaines, Kishwaukee, and West Branch DuPage rivers all rose 4 to 6 feet during the two-day period. The Fox River at Montgomery, East Branch DuPage River at Bolingbrook, and Illinois River at Morris, Ottawa, and LaSalle crested at their highest recorded stages. These rapid watershed rises also caused many area rivers to experience their highest peak discharge values.

Comparison to Similar Historical Event

Although heavy rainstorms (those producing ≥ 2 in. in a 24-h period) are not unusual in northern Illinois (Huff and Angel 1989), two consecutive days of ≥ 2 in. rainfall has only happened four other times in the climate record of Chicago's Midway Airport. Interestingly, one of these historical cases (12-13 September 1961) contained analogous spatial and temporal meteorological features to the 13-14 September 2008 event. Figure 10 shows a multi-panel comparison of 500-hPa heights and winds from similar temporal spacing periods during both events. With such similar upper-level features, it is no surprise that the surface tropical cyclones emerging out of the Gulf of Mexico also took similar tracks (Figure 11). The September 1961 event was not only ironic in its similar Julian day timing, but its meteorological similarities indicate that Illinois weather forecasters should be aware of this type of unusual and infrequent heavy rainfall event.

Regional Impacts

The record rainfall that occurred in northern Illinois created significant impacts across the region. President George W. Bush declared seven northeastern Illinois counties (Cook, DeKalb, DuPage, Grundy, Kane, LaSalle, and Will) disaster areas and by early October 2008, residents of these counties began to receive aid from state and federal sources (Hood, 2008). Four individuals died because of the flood-induced heavy rains.

The heavy rains lead to many flood-related issues across northern Illinois and northwestern Indiana. Communities along the Des Plaines, Chicago, DuPage, Fox, Little Calumet, Kankakee, and Illinois rivers experienced severe street and basement flooding. Over 2,000 homes were evacuated due to rising river levels and because flood levels were slow

to recede, they could not return to their homes for many days. In Cook County alone, more than 3,600 people were driven from their homes as water levels rose. After the waters slowly receded, residents were faced with cleaning up their homes and neighborhoods. Many lost most, if not all, possessions that were impacted by floodwaters. Large amounts of trash were found on city streets for weeks after the storm.

Chicago's Deep Tunnel, a system of large tunnels built under the city to hold 2.5 billion gallons of storm water runoff, filled by early Sunday (14 September 2008) forcing Chicago's Metropolitan Water Reclamation District to release storm runoff and untreated sewer water for the first time in six years. Four billion gallons of water an hour were released into Lake Michigan, and by end of the storm nearly 90 billion gallons of storm/sewer water was diverted to the Lake. This large release of untreated water led to concerns that sewage could find its way into water inlets. To counteract this potential problem Chicago and suburban communities that rely on Lake Michigan for drinking water enhanced chlorine amounts.

Transportation systems around the Chicago metropolitan area were highly impacted by the storm's floodwaters. As continuous rainfall occurred across the region Saturday into Sunday, a number of highways and interstates became overwhelmed with water. In northeastern Illinois parts of the Bishop Ford Freeway, I-90 and I-190 near O' Hare, and the Edens Expressway (I-94) north of downtown Chicago were closed for a number of hours. In northwestern Indiana, roads near the Little Calumet River were closed for several days. Interstates 65, and 80/94, a main east-west thoroughfare between the East Coast and Chicago, were flooded and remained closed to traffic until Tuesday, 16 September. Both Chicago airports delayed or canceled hundreds of flights over the weekend due to the almost continuous rainfall. Because of the interstate flooding, many individuals could not get to O'Hare either to pick up passengers or to catch flights. A number of metropolitan railroads had sections of track under water or impassible on Sunday. This slowed if not stalled the busiest freight railroad center in the United States for nearly 48 hours.

Agricultural areas outside of Chicago were also impacted. Mid-September is generally a period when corn and soybean crops are drying out before harvest. The heavy rains left fields saturated, and in many situations, large ponds developed. Luckily, most crops had matured by this point and the late growing season deluge did not significantly affect crop yields.

Additionally, the heavy rains impacted two major recreational areas in the region. Six Flags Great America theme park, located north of Chicago in Gurnee, and for the first time since it opened in 1934, Brookfield Zoo closed on Sunday. Many students received a three-day weekend as schools impacted by flooding were closed on Monday. North Park University (located near Chicago's north side) closed its dorms after losing power due to flooding.

SUMMARY

The 12-14 September 2008 rainstorm will be remembered for the unique meteorological conditions that created it, and the number of hydro-climatic records and flood-related

impacts across Northern Illinois. Anomalously high PW values associated with tropical moisture from two tropical storms (Lowell from the Pacific and Ike from the Gulf of Mexico) and a slow-moving cold front, were unique in the weather annuals for Chicago. Additionally, climate records indicate that a similar event occurred in 1961 with tropical moisture associated with Hurricane Carla. This unique and infrequent weather situation involving upper-level and surface meteorological features present, and their temporal progression, can be used by forecasters to anticipate non-convective heavy rainfall in Northern Illinois.

ACKNOWLEDGMENTS

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Figure 1. Surface isodrosotherms (solid, °F) valid at 0000 UTC 12 September 2008.

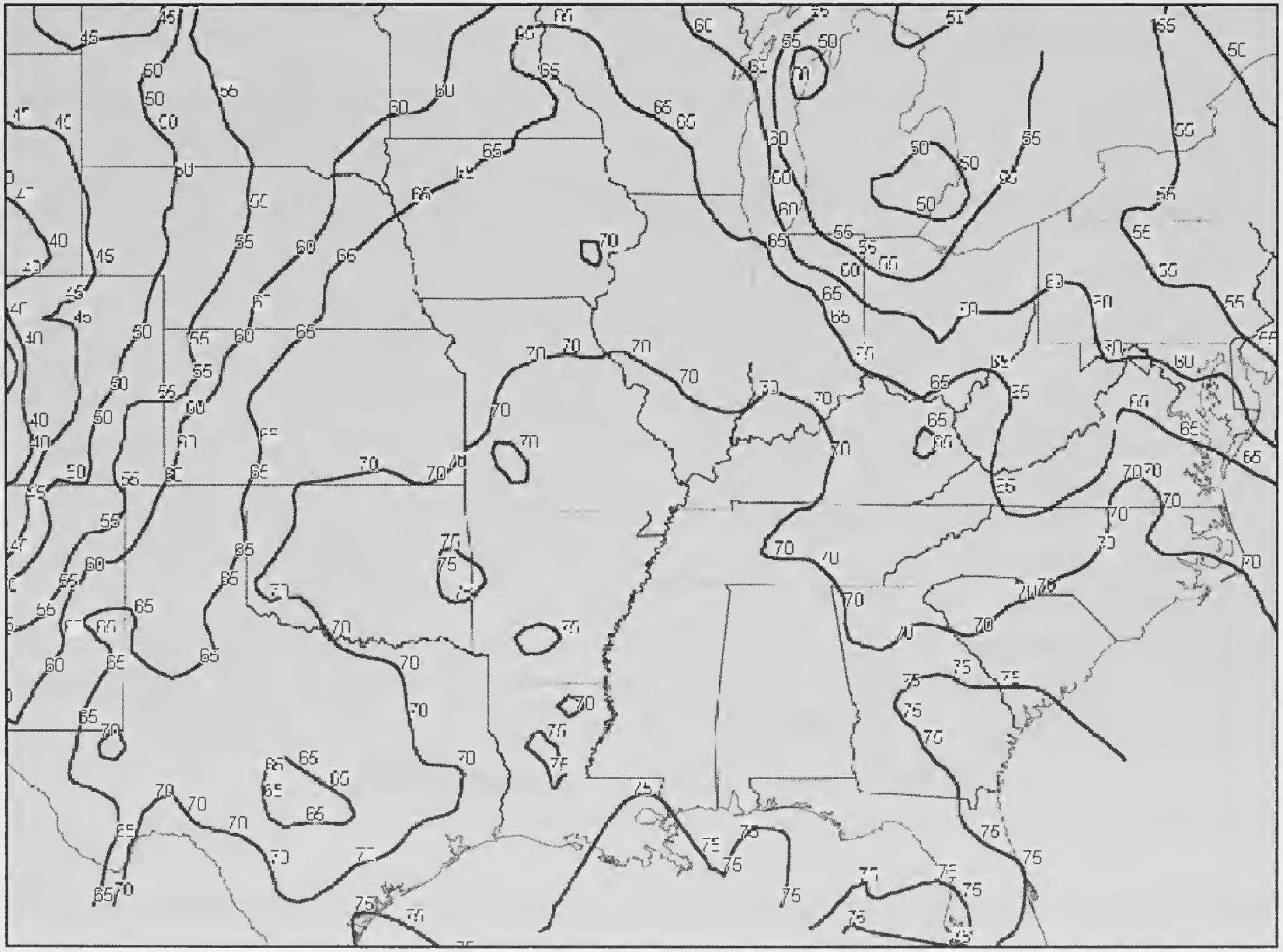


Figure 2. Time-series of precipitable water (PW, in) for the period 0000 UTC 12 September-0000 UTC 15 September 2008 for Davenport , IA and Lincoln, IL.

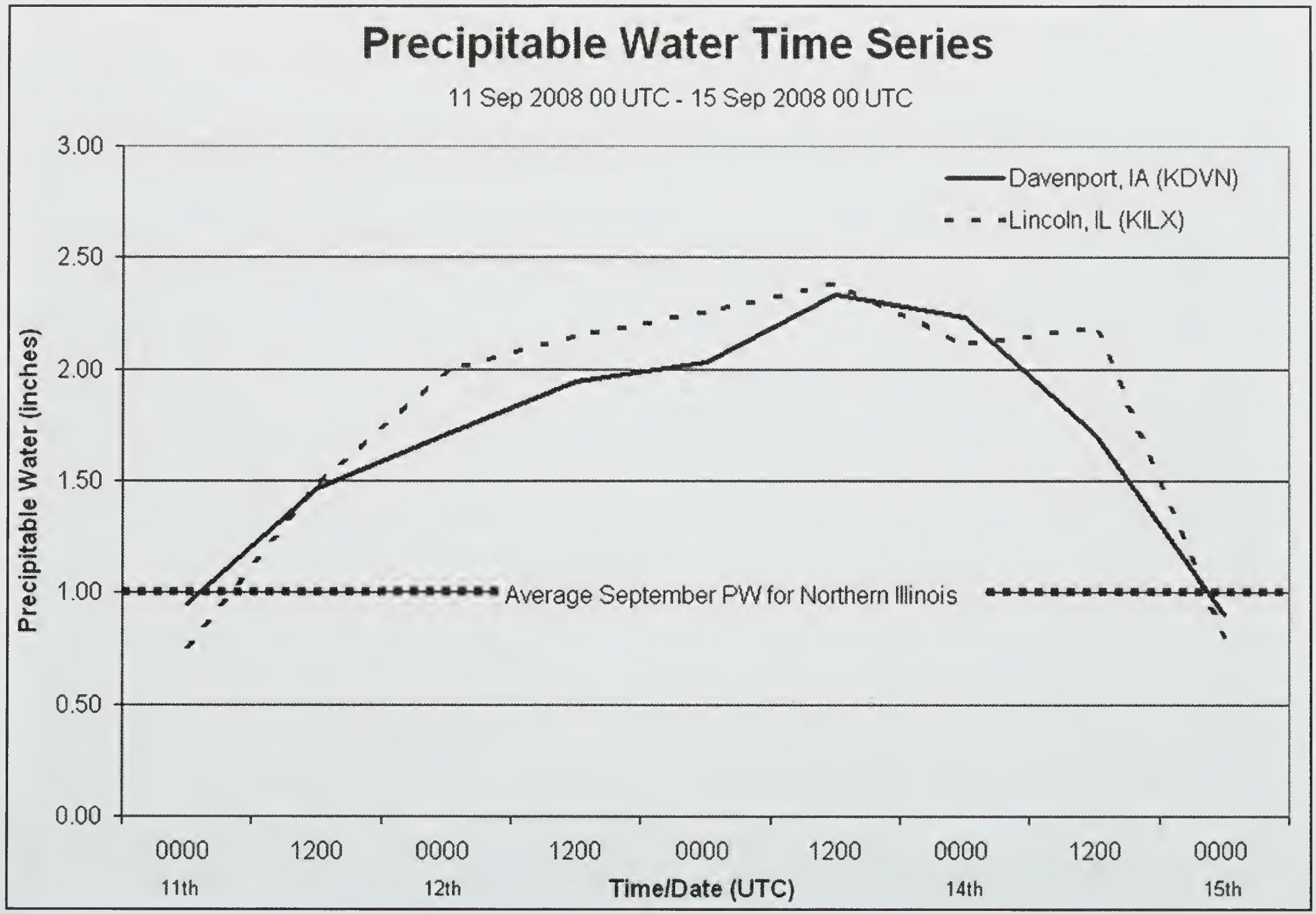


Figure 3. Surface isodrosotherms (solid, °F) and wind barbs (kt) valid at 1200 UTC 12 September 2008 (top), 1200 UTC 13 September 2008 (middle), and 1200 UTC 14 September 2008 (bottom).

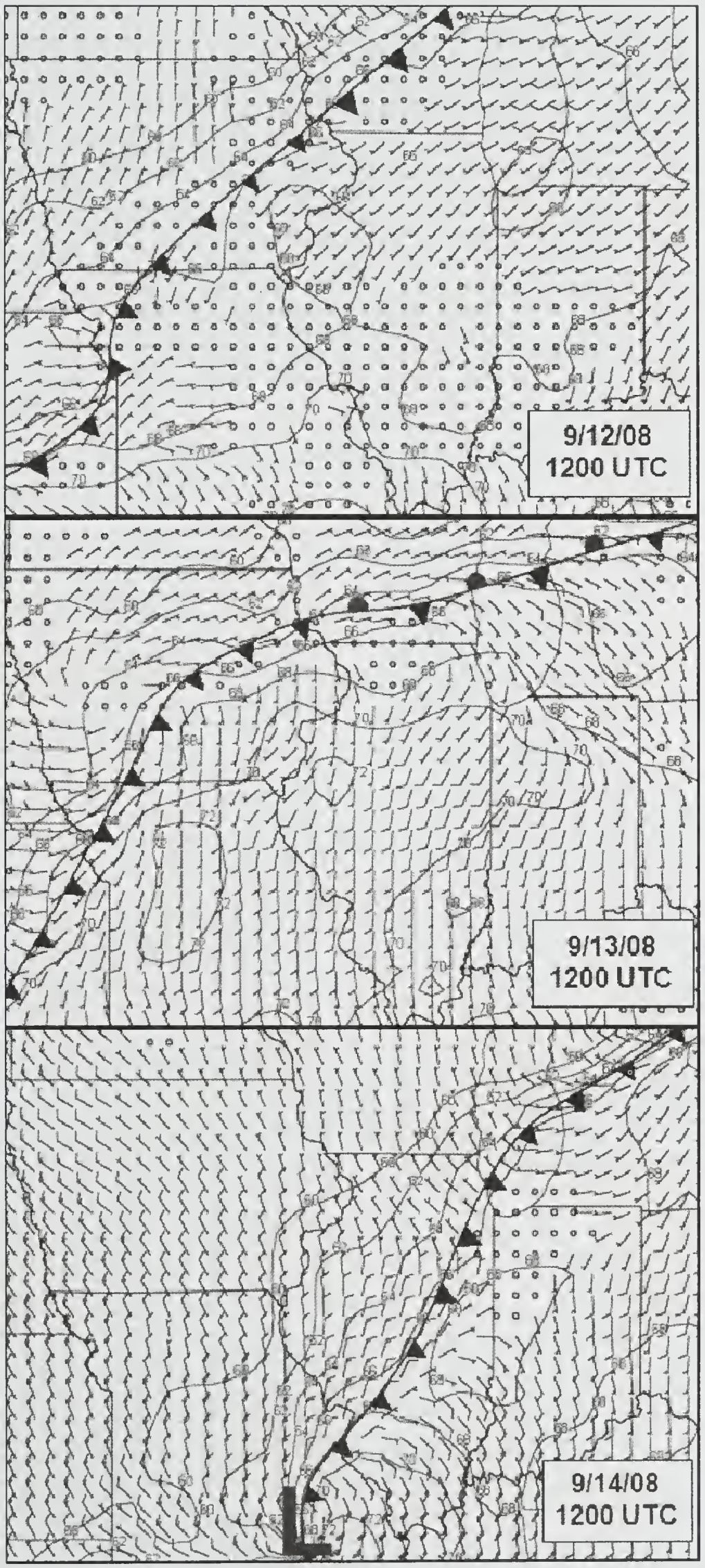


Figure 4. 0000 UTC 13 September 2008 soundings from KDVN (left) and KILX (right).

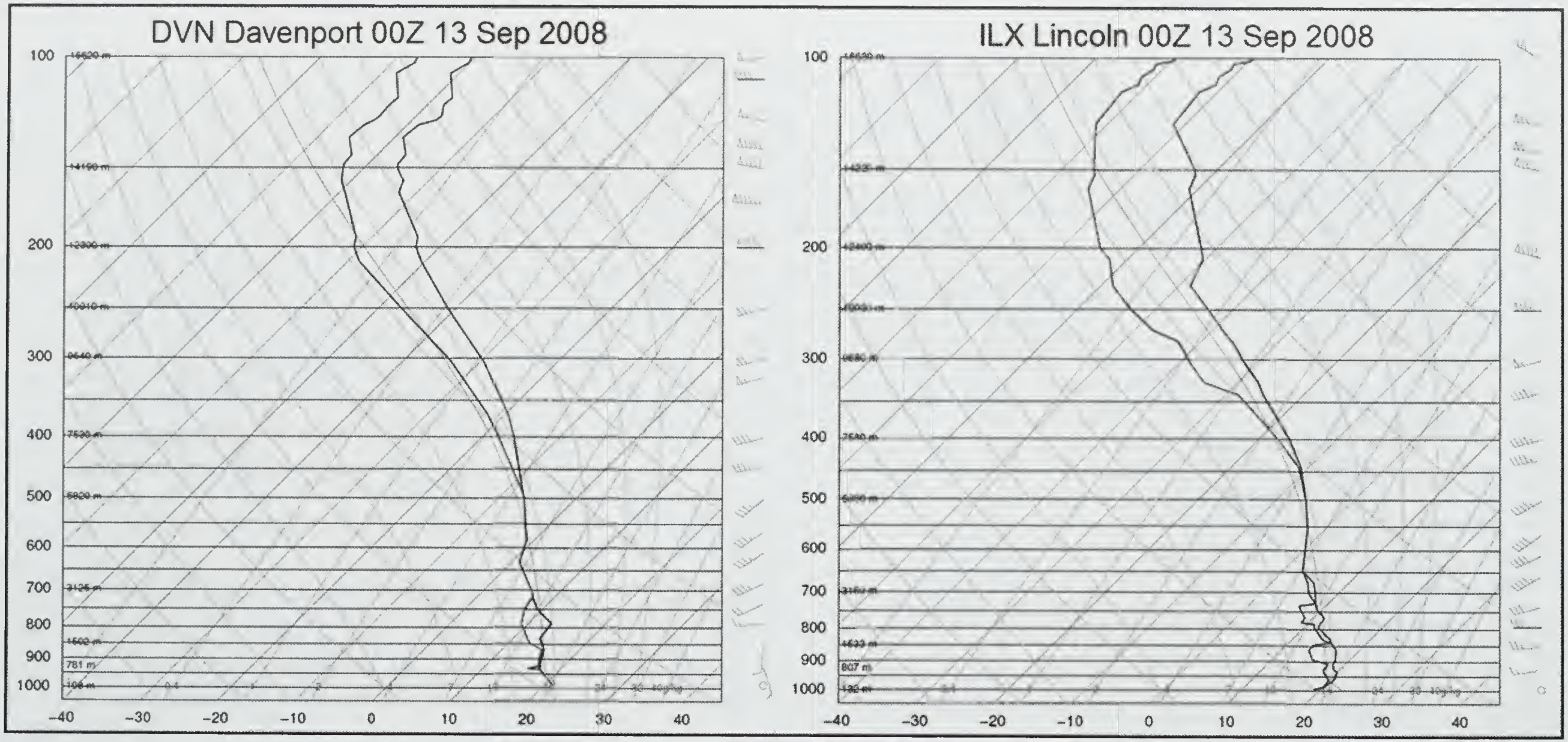


Figure 5. Rainfall return frequencies (icons/shading, years) over northern Illinois for the 12-14 September 2008 rainfall event (NOAA 2009).

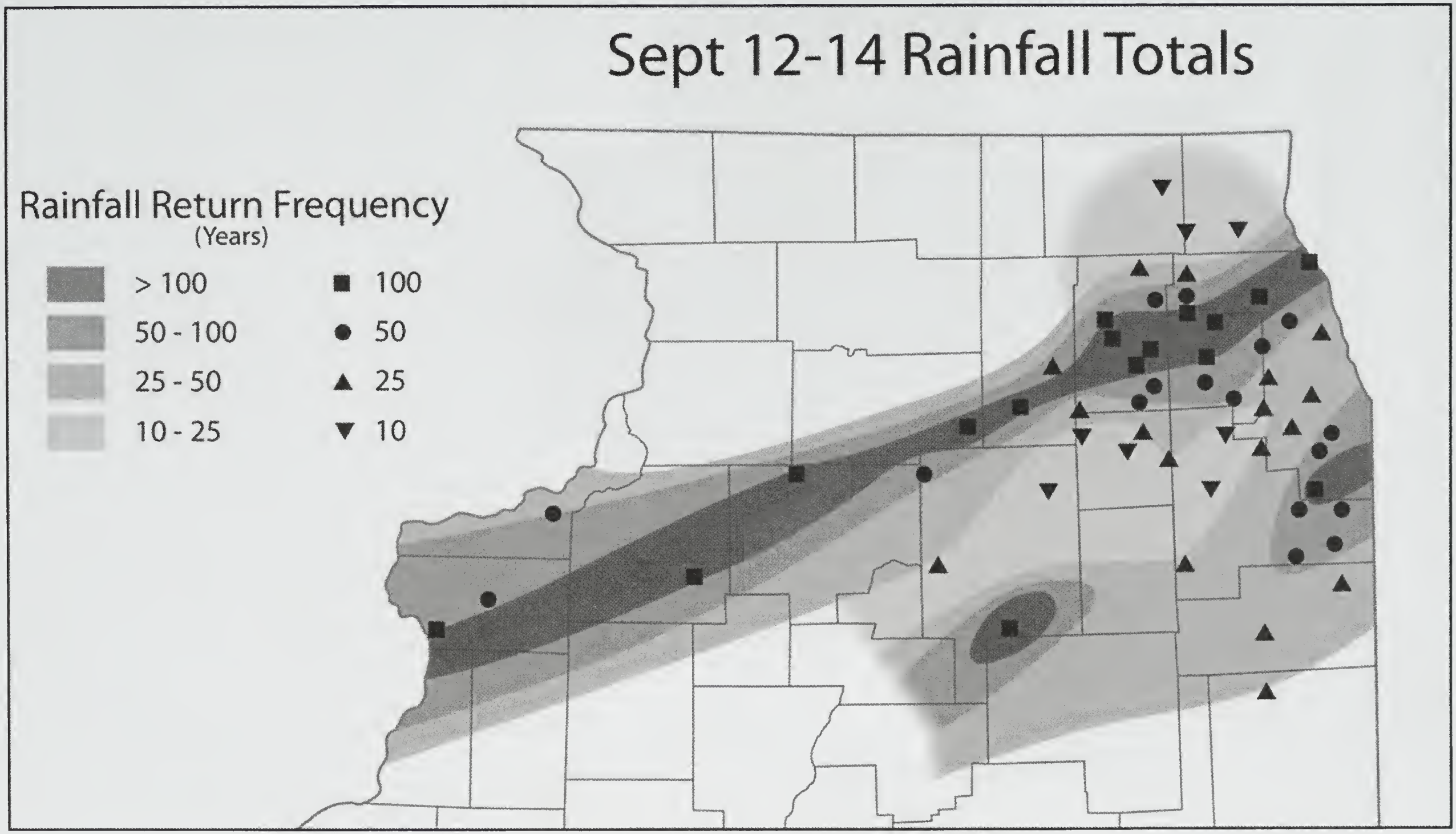


Figure 6. 12-14 September 2008 event total rainfall (in.) across northern Illinois and northwestern Indiana courtesy of National Weather Service and CoCoRaHS observations.

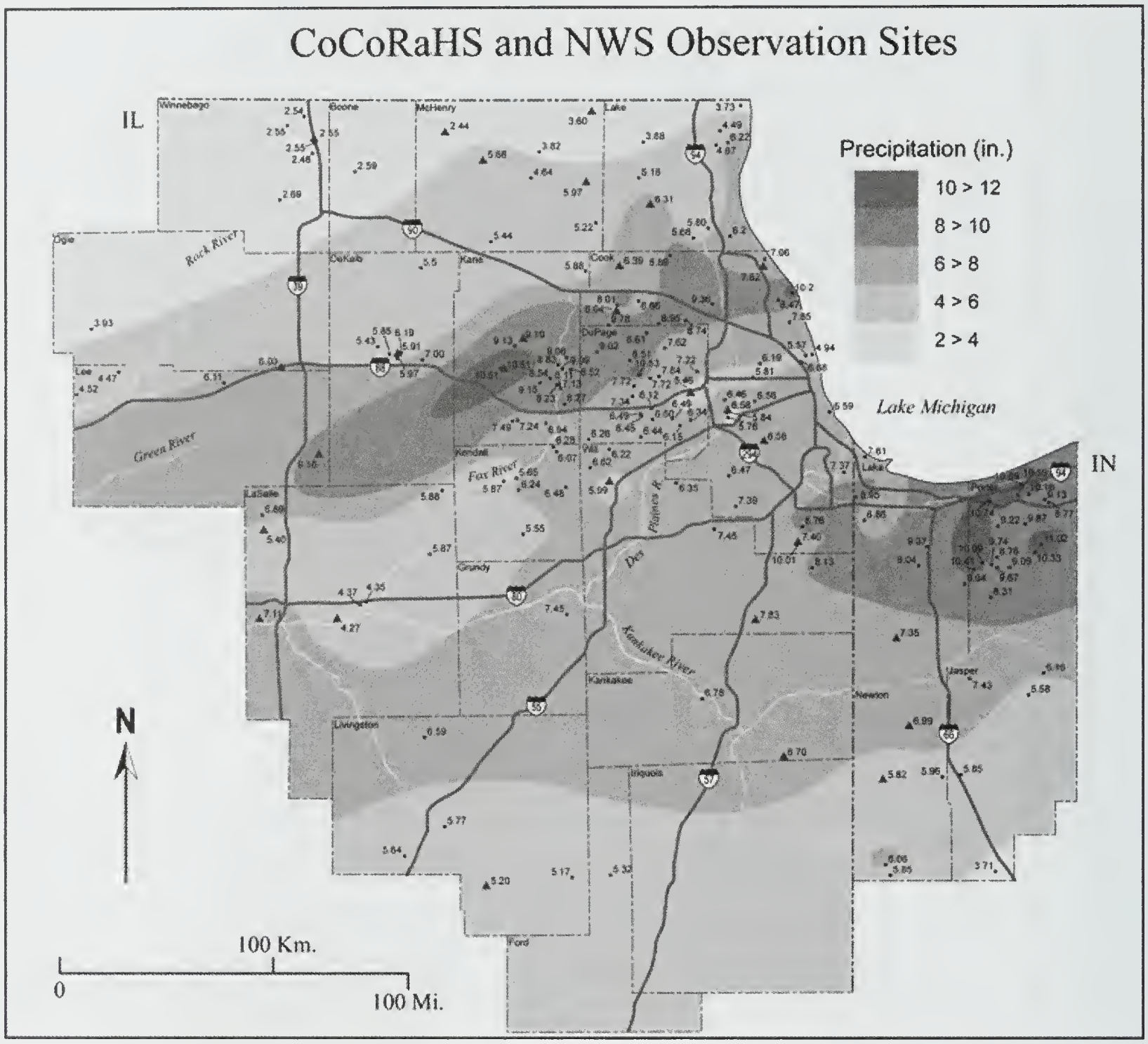


Figure 7. Hourly precipitation totals in inches from Moline, IL and Chicago O'Hare for the period from 0000 UTC 12 September to 0000 UTC 15 September 2008 (USGS 2009).

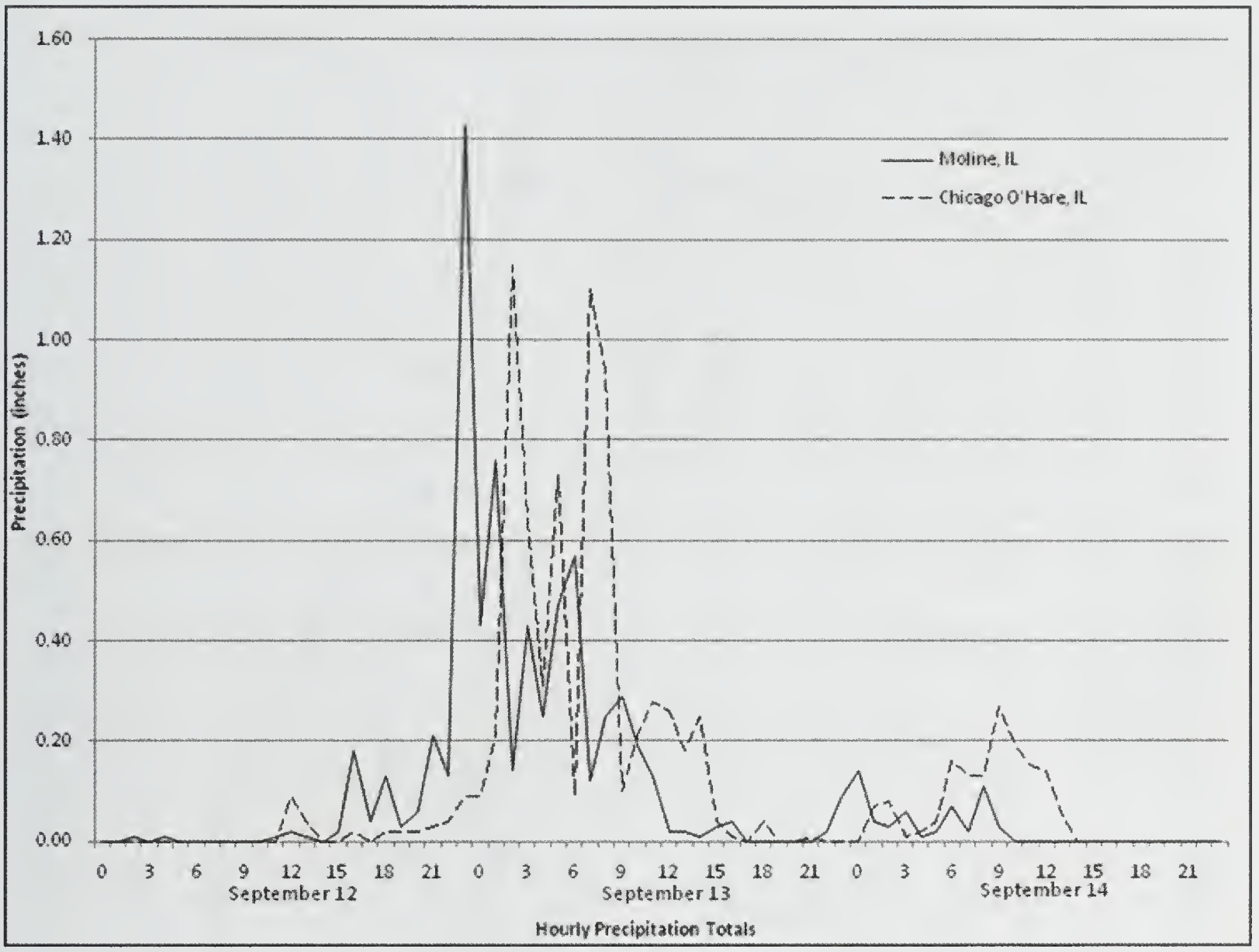


Figure 8. Peak streamflow return frequency (years) for northern Illinois for the 12-14 September 2008 rainfall event.

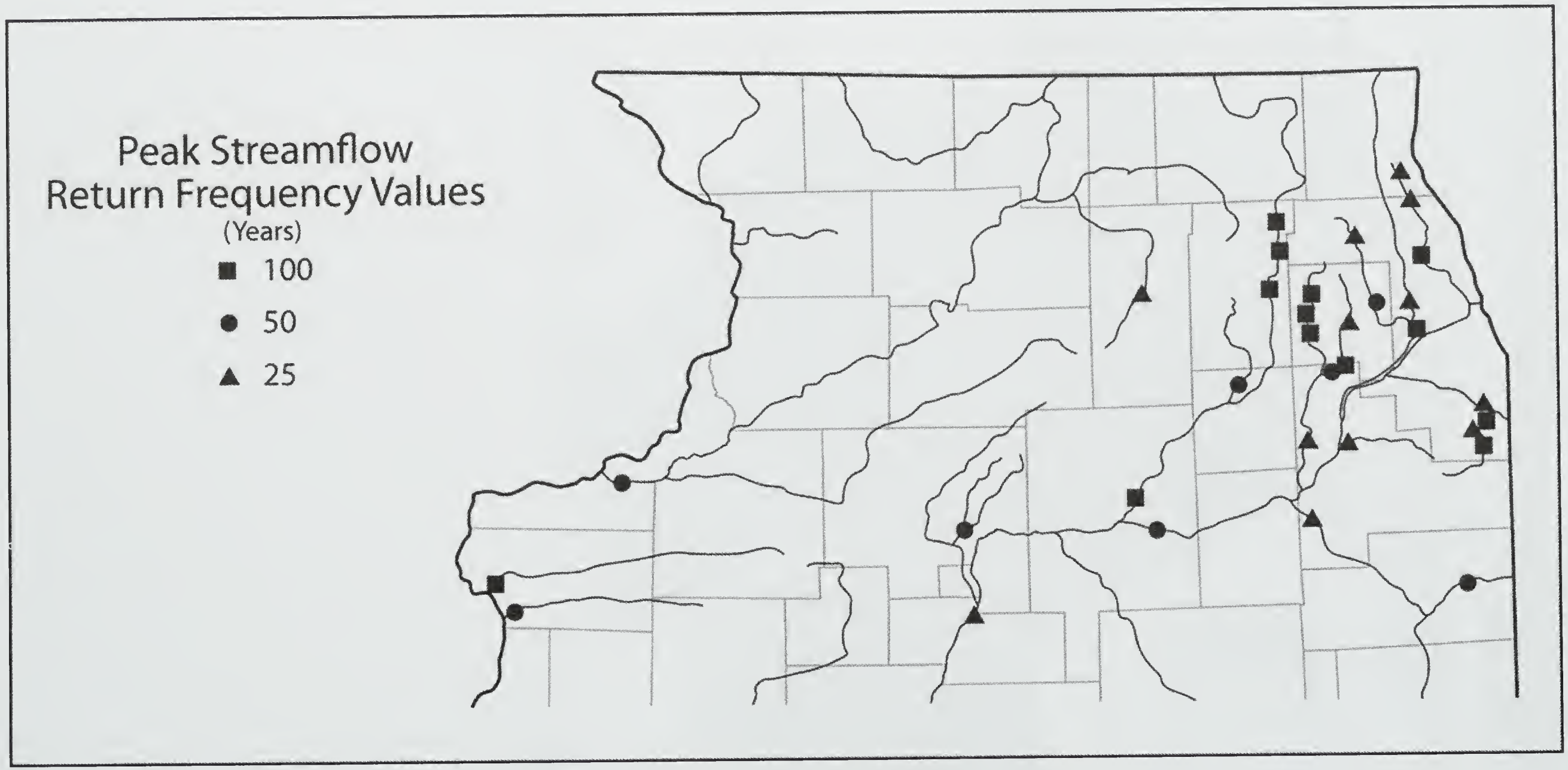


Figure 9. River stages (feet) for 10-20 September 2008 at various gauge sites in northeast Illinois.

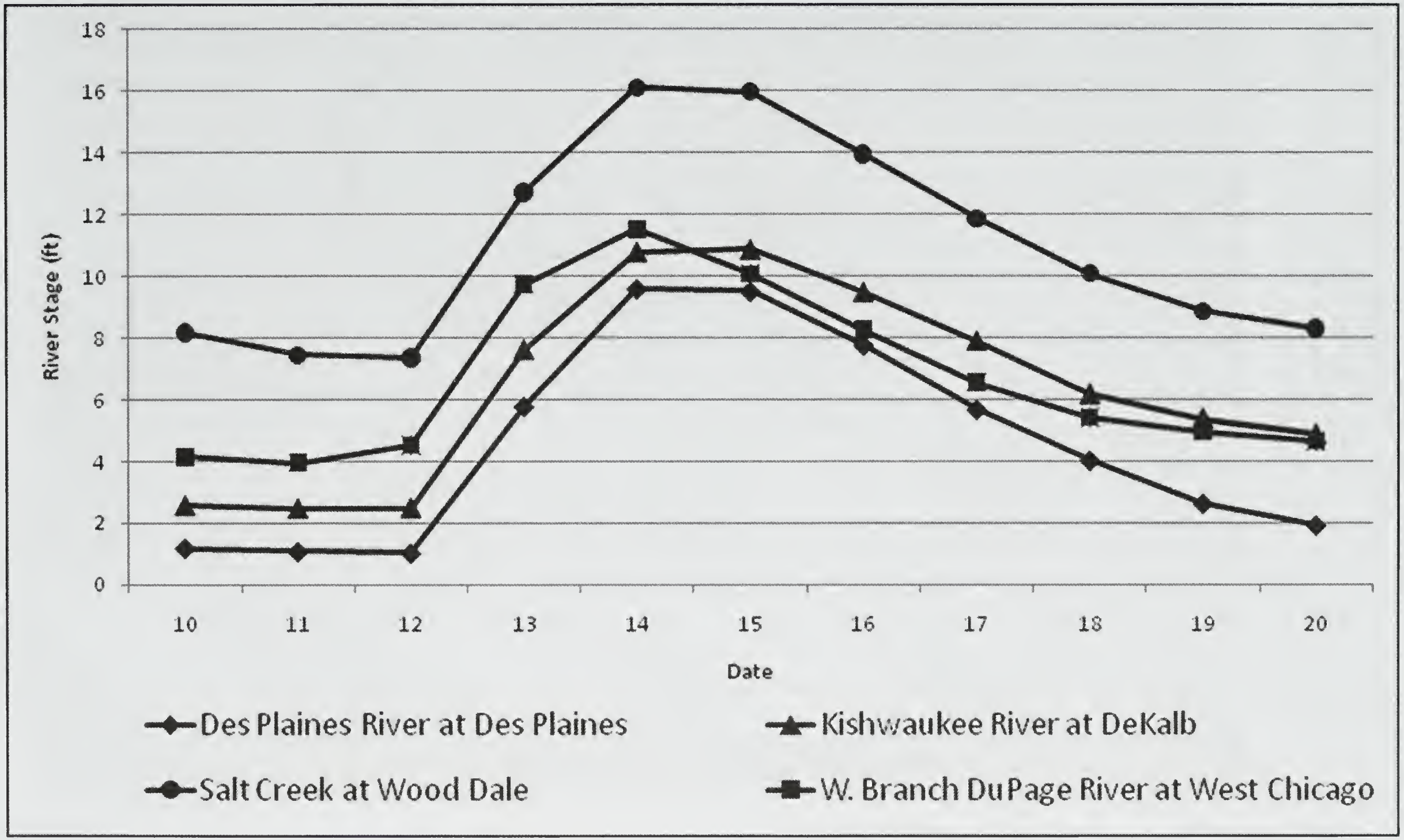


Figure 10. 500-hPa height thumbnail images for 11-14 September 1961 (left), and 12-15 September 2008 (right). Temporal progression is from top to bottom in 24-h intervals starting at 0000 UTC on the respective dates. Solid contours are geopotential height (ft on left, dam on right), dashed contours are isotherms (°C), and wind barbs are in kt. Images courtesy of NOAA's Daily Weather Map Series (left) and the Storm Prediction Center (right).

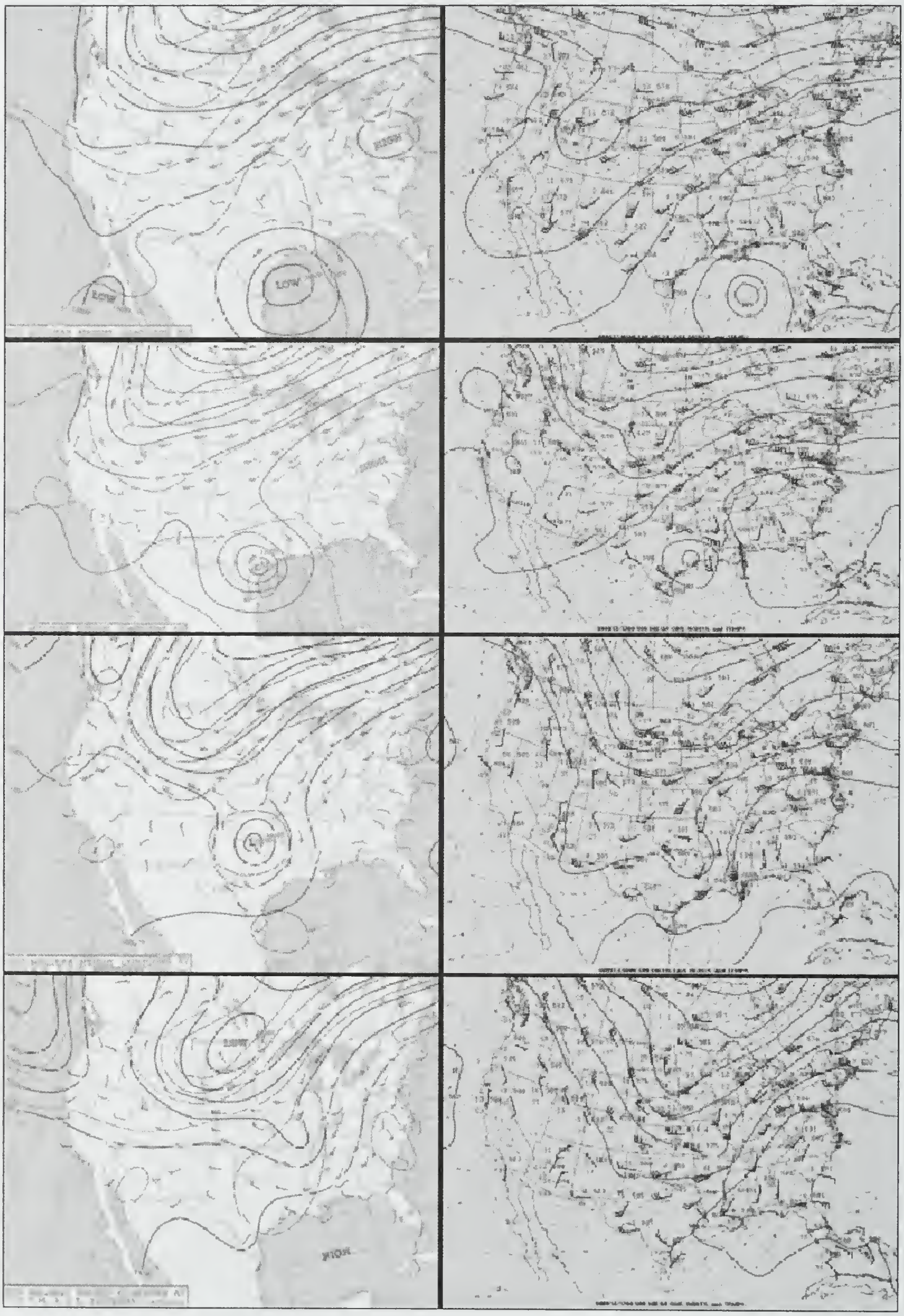
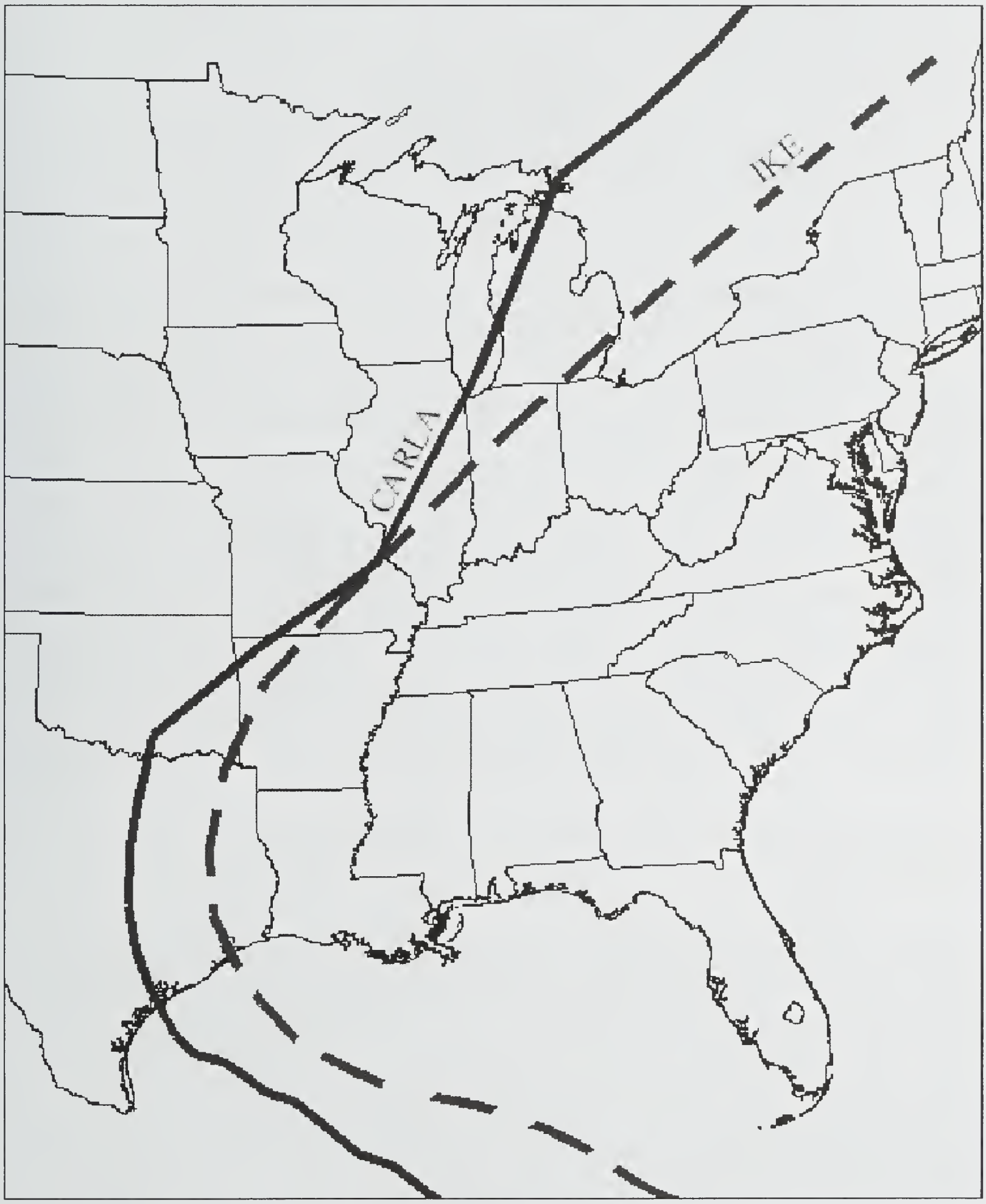


Figure 11. Surface cyclone tracks for Hurricane Ike (2008, dashed) and Hurricane Carla (1961, solid) that caused two inch or greater rainfall for two consecutive days at Chicago's Midway Airport.



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A Record Sequence of Four Severe Winters in Illinois

Stanley Changnon
Changnon Climatologist
Mahomet, Illinois
E-mail: schangno@illinois.edu

ABSTRACT

Four winters in Illinois during 2006-2010 caused high losses and were the only sequence of four severe winters since economic loss records began in 1949. Winter severity was defined by insured property losses of $100 million or more. The winter of 2006-2007 was severe largely because of major snowstorms and ice storms caused $118 million in property losses. The 2007-2008 winter had 14 winter storms creating record conditions coupled with low temperatures. Major losses occurred to transportation and extensive property losses totaled $253 million , the highest on record. The winter of 2008-2009 had near record low temperatures and heavy snowfalls that exceeded 50 inches across northern Illinois. The conditions killed 16 persons and created property losses of $172 million. The fourth winter, 2009-2010, had above normal snowfall in all parts of the state, and temperatures were below normal across the state. Impacts were very large on transportation systems, property, and power systems, property losses totaled $159 million. The 61 past winters during 1949-2010 had 15 winters with property losses >$100 million. The sequence of four such loss winters during 2006-2010 were a climate anomaly, potentially reflecting a shift in climate. Their property losses exceeded $0.7 billion.

INTRODUCTION

A series of four consecutive winters, each causing excessive property damages in Illinois, occurred during 2006-2010. The causes of the property losses and other impacts across Illinois in each winter were assessed. They were found to vary with some losses from major storms and others from extreme cold and/.or heavy winter snowfall. The winter loss data used was from the insurance industry and included all the insured property losses to homes, vehicles, and buildings. These data have been assessed and found to be carefully adjusted by insurance experts and allow justifiable temporal comparisons of losses in between years. Other impacts of the four winters were also identified including transportation systems, government expenditures, and human life.

The potential uniqueness of the four consecutive winters was assessed by comparing their high losses to property with past losses. Insurance records of property losses extend back to 1949, and the years with high losses comparable to those during 2006-2010. The potential relevance of the findings to the issue of climate change was considered.

DATA

The severity of Illinois winters was defined quantitatively using the economic losses caused during the winters. Historic records of the annual loss of lives due to winter conditions are not of sufficient quality to use in long-term temporal analyses of winter severity. Various measures of economic losses exist but the only measure that has quality and long duration is that recorded by the property insurance industry since 1949 (NRC, 1999). These records of property losses in each year have been systematically adjusted for changes over time and thus adjust for inflation, shifts in insurance coverage, and property changes over time in the storm areas.

The nation's property insurance industry in 1948 formed a group of specialists who had the responsibility of identifying all catastrophes, defined as events causing $1 million or more in insured property losses (PCS, 2007). For each such event in 1949 and all following years, they collected data on the date/s of occurrence, the state/s where the insured losses occurred, cause/s of losses, and amount of loss (dollars) of each catastrophe. Catastrophe losses have been found to represent 90 percent of all weather-produced property losses in the U.S. (Roth, 1996).

Experts in the property-casualty insurance industry have systematically analyzed, in each year since 1949, the historical catastrophe data to update the past catastrophe loss values to match the current year conditions. This annual assessment updated to 2010 resulted in a 61-year database allowing an unbiased comparison of recent catastrophe losses in Illinois with those in past years.

This annual loss adjustment effort is a sizable and complex task, requiring assessment of each past event. Three adjustment calculations are made to the original loss value for the year and locations of each catastrophe. One adjustment corrects for time changes in property values and the cost of repairs/replacements, and hence, this also adjusts for inflation. The second adjustment addresses the relative change in the size of the property market in the areas affected by the catastrophe using census data, property records, and insurance records. This action adjusts losses for shifts in the insured property between the year of a given storm's occurrence and the updated year (2010 in this study). The third adjustment is based on estimates of the relative changes in the share of the total property market that was insured against weather perils in the loss areas, done by using insurance sales records.

These adjustments were used to calculate a revised monetary loss value for each catastrophe so as to make it comparable to current year values. Thus, adjustments made in a recent year for all past catastrophes dating back to 1949 allow a fair assessment of their losses over time. An assessment of the insurance catastrophe values, and the temporal adjustment method used, found that demographic changes in various regions of the U.S. since 1949 were well related to the temporal adjustment values used by the insurance industry (Changnon and Changnon, 1998), and that the adjustment technique was financially sound (Changnon and Changnon, 2009). In 1999 the National Academy of Science assessed all types of hazard loss data in the U.S. and concluded that the property insurance data was the nation's best (NRC 1999).

The property losses in Illinois and estimated total loses for the winters of 2006-2010 are shown in Table 1. This reveals that each of the four winters had losses well in excess of $250 million and the 4-year total was $0.7 billion.

Table 1. Illinois property losses from the four winters between 2006 and 2010.

	Losses in millions of dollars				
Sector	2006-07	2007-08	2008-09	2009-10	Total
Property losses	118	253	172	159	702

WEATHER CONDITIONS IN THE FOUR WINTERS

The weather conditions in the four severe winters during the 2006-2010 period were assessed based on the departures from normal values for the winter months and the season. These departures for the mean temperatures, total snowfall, and number of severe winter storms in each winter are listed in Table 2. The ice storm severity is based on areal extent of ice in Illinois with a value of 1 when most (90%) of the state experienced ice storms, 2 when approximately 50% of Illinois had ice storms, 3 when ice storms covered 5 to 30 percent of the state, and 0 when none occurred. All four winters had above normal numbers of storms, above normal snowfall amounts, and below normal temperatures. Two winters had extensive ice storms and two had none. The magnitude of the winter values varied considerably between the four years.

Table 2. Departures from normal values for the four winters.

Conditions	2006-2007	2007-2008	2008-2009	2009-2010
Mean Temperature, °F				
December	+5.4	+0.0	-3.5	-1.0
January	-4.7	+1.4	-4.6	-3.8
February	-8.9	-5.2	+1.2	-5.1
Winter	-2.3	-2.2	-2.5	-3.3
Snowfall, inches				
December	-0.6	+5.5	+5.2	+5.7
January	-3.9	+0.2	+2.7	-0.7
February	+6.3	+8.2	-3.0	+5.2
Winter	+0.6	+4.5	+1.7	+3.4
Snowstorms, number				
December	+1	+6	+3	+2
January	-1	+1	+1	-1
February	+2	+3	+1	+2
Winter	+2	+10	+3	+3
Ice storm severity	1	2	0	0

2006-2007 Winter

The winter 2006-2007 brought several major winter storms across the United States. An early season, damaging winter storm occurred in Illinois on November 30-December 1, and it caused $54 million in losses. It brought thick layers of glaze in central and northern Illinois. In the ensuing 3 months more major storms occurred in Illinois. Two February storms in Illinois were very large and had very damaging snow and ice storms (Changnon and Kunkel, 2007).

The nation's 29th largest snowstorm on record (areal extent of snow) came on February 12-15. This storm brought heavy snowfalls, thick icing, and extremely high winds across central Illinois. Power outages and damages to telephone systems amounted to sizable losses and repair costs of $175 million, and total inured property damages of $0.35 billion. The state's third bad storm in 2006-2007 occurred on February 22-26. The resulting total winter snowfall in the northern third of Illinois was above 10 inches and a major ice storm occurred in northern Illinois, and this storm produced property losses of $29 million.

The winter caused thousands of homes to be without power for several days, and travel was difficult and dangerous from all three storms. Property losses in all three storms were classed as catastrophes by the insurance industry and totaled $118 million. Assessment of losses from the storms revealed 40 percent were to property. Transportation losses were 22 percent of the total, utilities losses and costs were 23 percent, government losses and costs were 8 percent, and retail business losses accounted for 7 percent of the winter total. The Chicago area experienced the greatest losses. Chicago's O"Hare Airport, the nation's busiest terminal, had 55 percent of its February flights delayed or cancelled.

2007-2008 Winter

The December 2007-February 2008 period in Illinois experienced a near record number of winter storms, plus a record number of rainstorms, several tornadoes, and every other form of severe weather that can occur in Illinois (Changnon et al.,2008). As a result, the state had 26 weather-related deaths, double the normal number, and excessive damages to vehicles, residences, and business. Communities and government agencies faced costly repair efforts, and many persons lost their homes due to major flooding from melting snow.

December had six winter storms, a new record high, and February had five winter storms, a value that tied as a record high. The 14 winter storms during the winter were one less than the record high value set in the winter of 1977-1978, and five storms in 2007-2008 had blizzard conditions.

The unique array of numerous storms, plus the extremes of temperature and numerous fogs, resulted in major losses and costs in four sectors. Property damages due to heavy snows, icing, and flooding led to losses of $520 million. Insured property losses were $253 million, the state's greatest winter loss in the 1949-2010 period. All forms of transportation suffered major losses and added costs that were estimated to be $435 million. Damages to power and communication systems led to repair costs totaling $492 million. Local, state, and federal agencies had to expend major sums for removal of snow and ice, and for road and highway repairs, and government expenditures totaled $217

million. Losses and costs resulting from the winter weather conditions in Illinois totaled $1.66 billion.

2008-2009 Winter

The winter of 2008-2009 in Illinois had several (nine) severe winter storms and many extremely low daily temperatures. Normally, the state has 4 severe winter storms in a winter. In northern Illinois the December-January period was the ninth coldest and sixth snowiest in the past 139 years. The climate winter, December-February, had a mean temperature that was 2.5° below normal and the fifth coldest since 1890 (Changnon and Kristovich, 2009).

This winter of bad weather conditions was the third in a row, following after the severe winter storms of 2006-2007 and the bad winter conditions of 2007-2008. The snowfall totals for the winter of 2008-2009 ranged from 50 inches in the extreme north to less than 5 inches in extreme southern Illinois. The northern sections had snow amounts that ranged from 10 to 25 inches above normal. Snowfall totals in central Illinois ranged from 10 to 20 inches, and were near normal. But south of a line from Quincy to Mattoon, all points had below normal amounts, revealing a large contrast across the state.

The winter of 2008-2009 created a myriad of impacts in eight sectors ranging from agriculture to retail business. The bad weather led to 16 deaths and injuries to 1,800 persons. Numerous power outages occurred, and the high costs of natural gas for heating impacted all residents. All forms of transportation were seriously affected, a key problem for Illinois since Chicago serves as the nation's hub for rail, airline, and truck operations. Many trains were delayed and some halted; vehicle traffic was slowed and often halted; and air travel was delayed at the state's major airports. Local and state government agencies suffered very high costs to remove snow and repair damaged roadways. The insured property losses totaled $172 million, and the winter's total losses and costs were estimated as $1.4 billion

2009-2010 Winter

This winter had six severe snowstorms but no ice storms. The winter's total snowfall ranged from 8 inches at Cairo to over 50 inches in Chicago, and all parts of Illinois had snowfall totals well above normal. Amounts in northern Illinois ranked as eighth largest in past 125 years. Continuous low temperatures led to a snow cover in central and northern Illinois that lasted for more than two months, from late December until the end of February. The number of days with snowfall exceeded normal values across Illinois. Monthly temperatures were below normal in all three months Changnon, 2010). The statewide winter snowfall total was 28.8 inches which is 3.4 inches above normal (Table 2).

The storms on December 7-8 and December 21-22 were confined to the northern third of the state. The December 25-26 storm was larger, and it produced totals above 10 inches in northern Illinois. The storm on January 6-8 was widespread, as was the storm on February 7-9. This storm produced more than 12 inches of snow in northeastern Illinois.

The impacts of the storms, cold, and snow cover led to $159 million in losses to property (houses, vehicles, and businesses). The heavy snows, numerous storms, low temperatures

statewide, and long-lasting snow cover in central and northern Illinois produced a myriad of other impacts in Illinois, some of a serious nature. These included damages to various property, transportation problems, power outages, and costly efforts to deal with the weather problems. Anther problem included flooding that resulted from the melted snowfall.

HISTORICAL PERSPECTIVE

The insured property losses during the winters of the 1949-2010 period were examined to gain a perspective on the 4-winter sequence of high losses during 2006-2010. Insurance loss experts indicated that property losses over $100 million in a winter were truly major, severe seasonal losses. Inspection of the 61 winter loss values revealed that more than 50 percent (34) were $25 million or less. Fifteen winters had losses of $100 million or more, and the next highest losses were $81 million and $78 million. This information suggested that winters with losses greater than $100 million could be considered extremely severe.

The 15 winters with losses >$100 million are listed in Table 3. Inspection of the temporal distribution of the 15 winters reveals there were four periods when two consecutive winters occurred and three years were single events. The 2006-2010 sequence was the only 4-winter sequence in the past 661 years.

Table 3. Winters during 1949-2010 that had property losses of $100 million or more in Illinois.

Winter	Property Loss	Winter	Property Loss	Winter	Property Loss
1949-50	$227	1965-66	$135	2004-05	$113
1950-51	$136	1970-78	$129	2006-07	$118
1956-57	$238	1978-79	$211	2007-08	$253
1959-60	$115	1992-93	$159	2008-09	$162
1960-61	$115	1993-94	$186	2009-10	$159

The eight most damaging winters are listed in Table 4. This reveals that three of the four winters during 2006-2010 had extremely high losses. Clearly the winters of 2006-2010 were unique in timing and in the magnitude of their damages.

Table 4. Eight winters with the greatest losses during 1949-2010.

Rank	Loss, $millions	Winter	Rank	Loss, $millions	Winter
1	253	2007-2008	5	211	1978-1979
2	238	1956-1957	6	186	1993-1994
3	227	1949-1950	7	162	2008-2009
4	224	1959-1960	8	159	2009-2010

SUMMARY

This study assessed four recent consecutive severe winters in Illinois, those during 2006-2010. Winter severity was defined by the magnitude of property losses, and winters with $100 million or more in insured property losses were identified as being severe.

The winter of 2006-2007 was severe largely because of major snowstorms and extensive ice storms, causing $0.9 billion in losses, mainly to property, power systems, and transportation systems. The 2007-2008 winter had 14 winter storms creating record stormy conditions coupled with low temperatures. Major losses occurred to property and transportation in Illinois, and the losses totaled $3.5 million, the highest winter loss during 1949-2010. The winter of 2008-2009 had near record low temperatures and heavy snowfalls that exceeded 50 inches in northern Illinois. The winter conditions impacted eight sectors, killed 16 persons, and created property losses totaling $172 million. The next winter in 2009-2010 had above normal snowfall in all parts of Illinois and winter temperatures were below normal. Resulting impacts were very large on transportation systems, property, and power systems, and property losses were $159 million.

Examination of past winters during 1949-2010 showed that 15 winters had caused >$100 million in insured property losses. On four occasions there had been two consecutive winters. The four consecutive winters during 2006-2010 formed the only four in a row sequence found in the past 61 years, revealing a climate anomaly6. The four winters also caused very high losses. Collectively, their occurrences may be a reflection of an on-going change in climate.

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The Effects of Host Diet on *Eimeria falciformis* in Mice

Brett Prater and T.E. McQuistion
Department of Biology, Millikin University, Decatur, Illinois 62522

ABSTRACT

Thirty-five six-week-old ICR® female mice were randomly placed in five groups. Each group consisted of seven mice with nearly equal body weights housed in one cage. The mice were given experimental diets of Lab Diet®, Puppy Formula®, Whole Corn, Suet Plus®, and Timothy Grass Pellets® one week prior to inoculation of 760 sporulated oocysts of *Eimeria falciformis* and continued until 12 days after parasite inoculation. The food rations had different levels of crude protein, fat, and fiber. Oocyst production was measured from Day 8 to Day 12 postinoculation.

The results demostrated that diet affects oocyst output. A diet high in protein (Lab Diet® and Puppy Formula®) resulted in the greatest oocyst production while a diet high in carbohydrates (corn) and fat (Suet Plus®) resulted in lower oocyst production.

INTRODUCTION

Coccidian parasites in the genera *Isospora* and *Eimeria* are common in vertebrate hosts. They have a direct life cycle and are mostly host specific. The effects of host diet on coccidian infections has been extentively studied in chickens and other poultry because of the parasite's economic importance to the poultry industry (Willis and Baker, 1981). However, there are few reports of the effects of host diet on coccidian infections in mammalian hosts. Although grain and seeds constitute much of their normal diet, mice are omnivores. Living among human habitation, their diet can vary widely from grain and plant material to dairy products, fruits, and even meat. *Eimeria falciformis* is host specific in mice and is highly pathogenic causing morbitity and mortality with the ingestion of only 1000 sporulated oocysts (Mesfin and Bellamy 1978). This study was designed to determine the effects of a high fat, high protein, or high fiber diet on oocyst production of *E. falciformis* infections in outbred mice.

MATERIALS AND METHODS

The Parasite

A pure isolate of *Eimeria falciformis* was diluted with distilled water to a concentration of 1000 sporulated oocysts per 1 ml of distilled water. Ten 5 week-old female ICR mice were each given 0.5 ml of the inoculum *per os* (500 oocysts/mouse). The mice feces were collected on Days 8-12 postinoculation (PI) and mixed with 2.5% (w/v) $K_2Cr_2O_7$. Air was pumped through the fecal- $K_2Cr_2O_7$ solutions for five days to allow the oocysts to

sporulate. The fecal- $K_2Cr_2O_7$ solutions were pooled and this solution served as the stock inoculum for the experiment conducted two weeks later.

Preparation of Parasite Inoculum

The stock $K_2Cr_2O_7$ solution containing sporulated oocysts of *E. falciformis* was centrifuged (450g for 10 min) to remove the $K_2Cr_2O_7$ and diluted with distilled water to obtain 760 oocysts/0.5 ml. One half milliliter was inoculated *per os* into each of 35 six-week-old female, ICR®, pathogen free, outbred mice (Harlan Laboratories, Inc., Indianapolis, IN) using a one cc tuberculin syringe fitted with a two inch, curved feeding needle with a 2.25 mm ball diameter (Popper & Sons, Inc., New Hyde Park, NY).

Experimental Design

Thirty-five six-week-old ICR® female mice were randomly placed in five groups. Each group consisted of seven mice with nearly equal group body weights and housed in one cage. The mice were housed in a room maintained on a 12-hour day-night cycle (8:00 AM-8:00 PM), 22°C ambient temperature and 50% humidity. Each group was given an experimental diet and water ad libitum one week prior to parasite inoculation and continued on the regimen until the completion of the experiment. One group was given Timothy Grass Pellets® (Standlee Hay Co., Inc., Eden, ID), another group was given Suet Plus® (Wildlife Sciences, LLC, Chaska, MN), a third group received Puppy Formula® (Diamond Pet Foods, Meta, MO), the fourth group received Lab Diet® (PMI Nutrition International, LLC, Brentwood, MO), and the fifth group was given Whole Corn (Agrimaster®, Janesville, WI). The relative amounts of protein, fat, and fiber are listed in Table 1.

Pine wood shavings were used for bedding material for the mice from the time they arrived until Day 7 postinoculation (PI). On Day 7 PI all mice were placed in clean cages fitted with wire screen floors, 7 mm square and raised approximately 25 mm above the bottom of the cage to collect the feces. A small amount of water was added to the bottom of the cage to keep the feces moist and the oocyst viable. Feces collection took place the same time each day from Day 8 PI to Day 12 PI. Each day during feces collection, the mice were placed in a new, clean cage with a clean wire screened floor. The feces from each cage were mixed with 2.5% $K_2Cr_2O_7$, homogenized in a Waring blender for 10 seconds, strained through 40 and 60 mesh sieves, and the volume measured in a graduated cylinder and recorded. Approximately 50 ml of the fecal- $K_2Cr_2O_7$ solution was retained to determine oocyst concentration later using a McMaster counting chamber. The average oocyst count for each mouse in each dietary group each day after parasite inoculation was calculated using the following equation:

$$\frac{\left[\left(\frac{C_1+C_2}{0.3}\right) \times 10\right] \times Y}{7}$$

where C_1 is the total oocyst count on the left side of the counting chamber, C_2 is the total oocyst count on the right side of the counting chamber, 0.3 is the total volume in ml from each side of the McMaster counting chamber, 10 is the total ml of the dilution factor, Y is the total volume in ml of fecal- $K_2Cr_2O_7$ suspension, and 7 is the number of mice in each dietary group.

RESULTS

Host Diet vs. Oocyst Production

Oocyst production in the mice was compared from Day 8 PI to Day 12 PI among the five experimental diets (Table 1). Mice infected with *E. falciformis* and given Lab Diet produced the most oocysts of any experimental group reaching a peak oocyst production on Day 9 PI of 6.1 million oocysts and resulting in a total oocyst production of the 5 day patent period of 12.9 million oocysts (Fig. 1). Mice given Puppy Formula showed the second highest oocyst output with a peak oocyst production on Day 9 PI of 4 million oocysts and a total production during the patent period of 8.5 million oocysts. Mice with a Suet diet had a peak oocyst production on Day 9 PI of 2.4 million oocysts and a total oocyst output of 4.9 million oocysts. Mice given Whole Corn showed a peak oocyst production on Day 9 PI of 1.4 million oocysts and a total oocyst output of 2.8 million oocysts. The mice given only Timothy Grass had a high mortality rate. Two mice on the Timothy Grass diet died before given the parasite and four additional mice died during the prepatent period of the parasite. Only one mouse lived to produce oocysts during the patent period (10,000 oocysts on Day 9 PI and 80,000 oocysts on Day 10 PI). The remaining mouse in the Timothy Grass group died on Day 10 PI.

A two-way analysis of variance without replication was used to compare total oocyst counts for each dietary group and Day 8 PI to Day 12 PI. Because of the large mortality among the Timothy Grass group, it was excluded from the statistical analysis; the df = 3.

There was a trend towards significance ($F = 2.86$, $P = 0.08$) when comparing food rations to total oocyst production and there was a significant difference when comparing oocyst production between groups by individual days postinoculation ($F = 4.94$, $P = 0.013$).

Body Weights

Body weights were compared before and after the experiment for each group except the Timothy Grass group because of its 86% mortality (Fig. 2). The initial individual body weights for each group ranged between 22-30 grams with average group body weights ranging from 24.8 to 28.4.

Based on a T-test assuming equal variance, the Suet group showed an average body weight loss, although not significant, from 24.8 to 22.8 gms. The Whole Corn group had significant average body weight loss, 28.4 to 24.2 gms ($t = 2.93$, $P = 0.01$). Conversely, mice fed the Puppy Formula ($t = 10.10$, $P < 0.01$) and Lab Diet ($t = 5.71$, $p < 0.01$) gained weight significantly, 25 to 32.7gms and 25.4 to 33.1 gms respectively.

DISCUSSION

Development of a parasite may be affected by nutrition of its host both directly by the supply of growth factors and nutrients, and indirectly through altered environmental conditions in the host, such as the physiological state, ion concentration, immunological state, or bacterial fauna (Kretschmar 1968). Mice provide an excellent model to study the nutritional requirements of coccidia in a mammalian host because of their varied diet. Frandsen (1983, 1985) demonstrated that rats on a low protein diet and infected with concurrent infections of *Nippostrongylus brasiliensis* and *Eimeria nieschulzi* had less

weight gain and increased severity of the effects of the parasitic infections than infected rats with a high protein diet. Although anorexia was a primary symptom of the parasitic infections and a major factor in the reduction of dietary protein intake for the rat host, it was critical in the rats with a low protein diet. The mice in this study given Puppy Formula with a crude protein content greater than 31% demonstrated significantly greater numbers of oocysts than mice fed Lab Diet with less than 22% protein and both groups showed comparable weight grains. Becker and Morehouse (1936) tested multiple diets including various levels of protein using *Eimeria miyairii* in rats. Although they reported slightly higher oocyst production in rats given a high protein diet compared to a "normal" diet, their study used only 5 rats in each group and the higher protein diet was supplemented with casein and Steenbock's ration for protein.

Mice given the Suet ration with a fat content of greater than 35% produced significantly fewer oocysts than groups on Puppy Formula or Lab Diet that had low fat content of 3% and 4% respectively. However, the Suet fed mice also showed weight loss during the infection period. Yang et al. (2006) found the opposite results in chickens infected with coccidia. Chickens infected with *Eimeria tenella* and given diets supplemented with saturated fatty acids had higher mortality (and more oocyst production) than chickens fed diets without oil. The mice with the corn diet, high in carbohydrates and comparatively low in protein, fat, and fiber also lost weight during the experiment but also showed comparatively low oocyst production. The group given Timothy Grass Pellets apparently had too little nutritional value to sustain their metabolic rate because they began dying before the parasite challenge.

This study suggests a balanced or high protein diet that promotes growth and weight gain for the mammalian host also promotes the reproductive potential of the coccidian parasite.

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Table 1. Diets used in this study with contents of crude fat, crude protein, and crude fiber amounts.

	Timothy Grass Pellets®	Suet Plus®	Puppy Formula®	Lab Diet®	Whole Corn
Protein	<8%	<5%	>31%	<22%	<6.5%
Fat	<1.8%	>35%	<3%	<4%	<4%
Fiber	>35%	<8%	<10%	<8%	<5%

Figure 1. Average number of oocysts produced per mouse on experimental ration per day postinoculation with *Eimeria falciformis*.

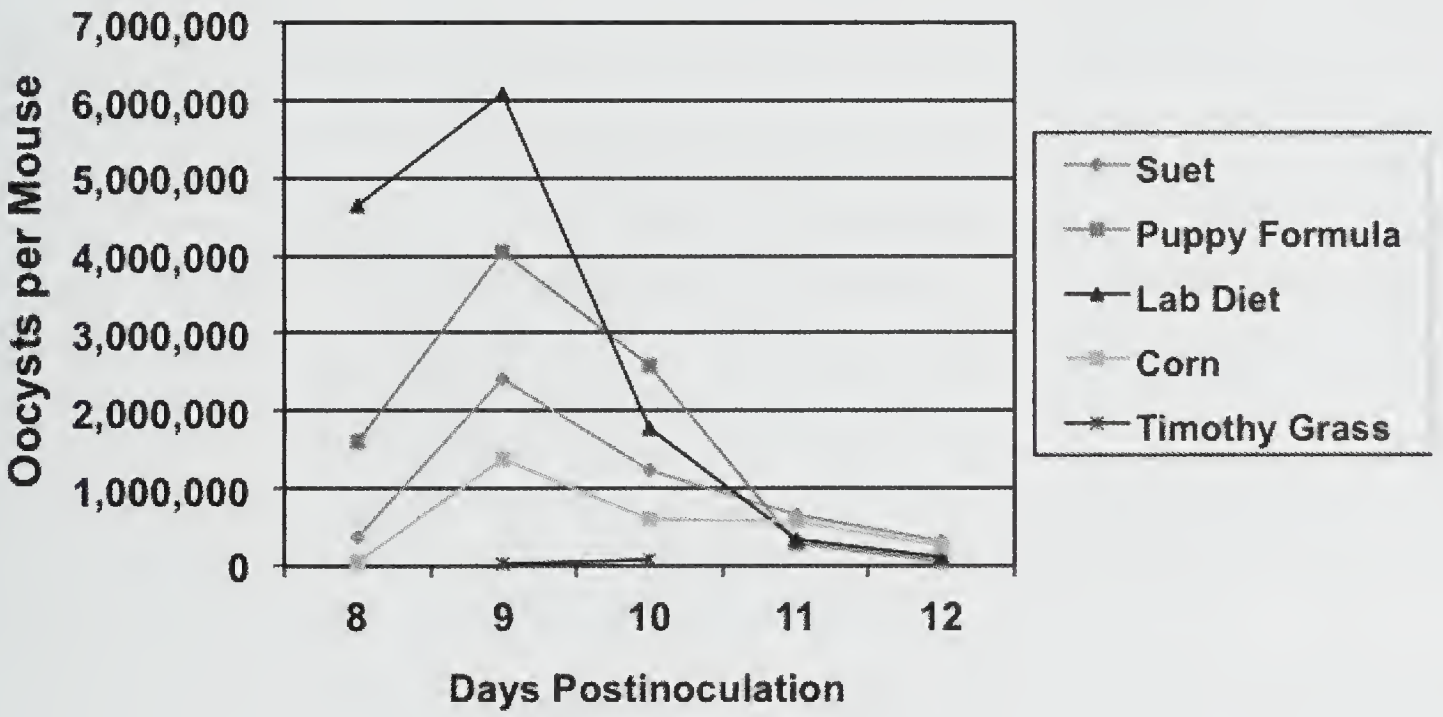
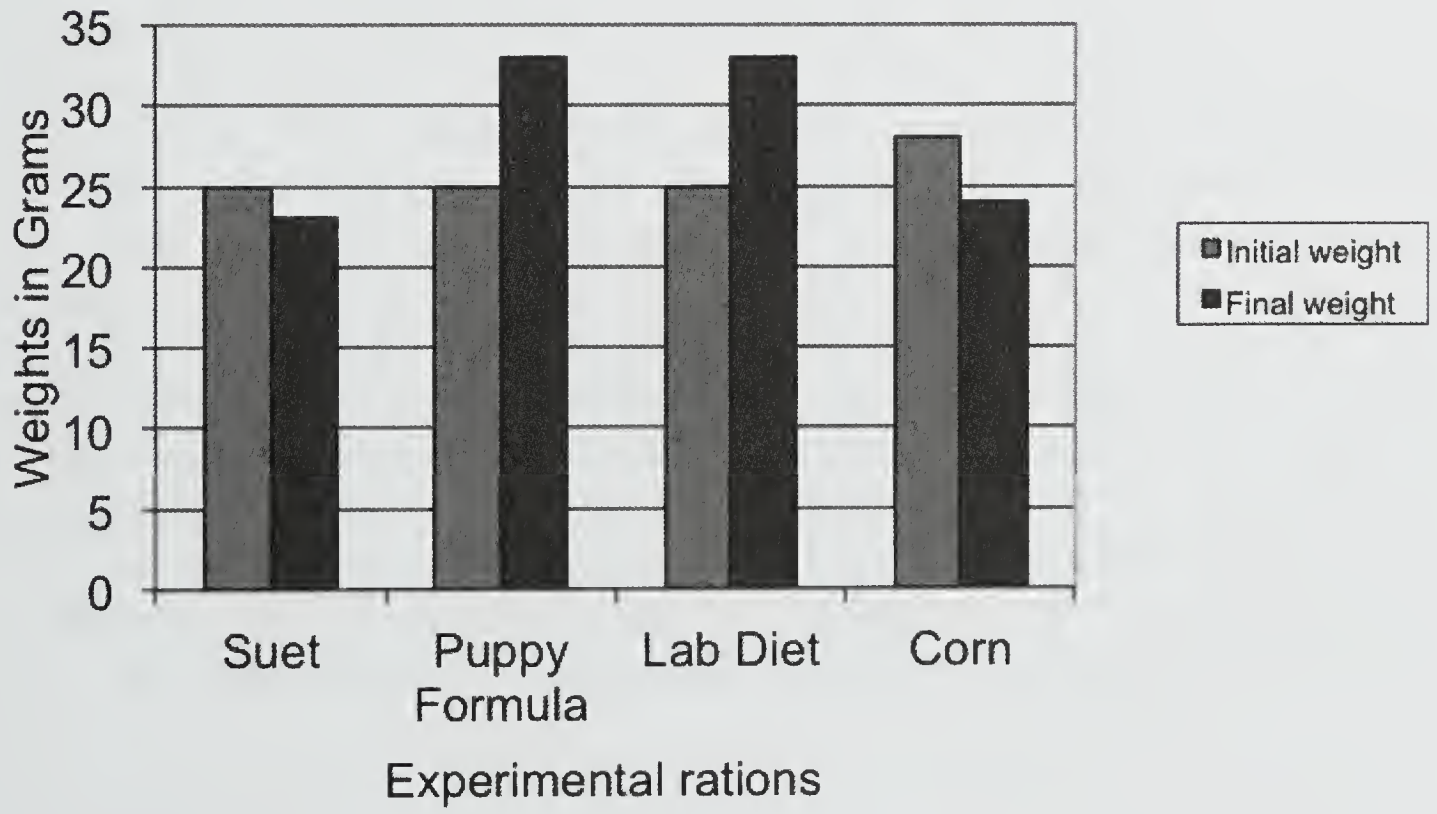


Figure 2. Comparison of average body weights of mice one week before inoculation of *Eimeria falciformis* (initial weight) and on Day 12 postinoculation of *Eimeria falciformis* (final weight).



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Assessing the Effectiveness of a Wet-Lab PCR Simulation in Biology Education

Jane M. Drake and Kelly J. Barry
Biological Sciences, Southern Illinois University Edwardsville

ABSTRACT

Polymerase chain reaction (PCR), a technique for amplifying small amounts of DNA, has revolutionized molecular biology. PCR has had a profound impact on how scientists study and manipulate DNA and consequently, it is increasingly incorporated into science curricula. The precise nature of the technique, however, can make it extremely challenging in the inexperienced hands of high school and undergraduate students. The number of steps involved, need for sterile technique, and the handling of extremely small volumes all make PCR cumbersome for students. Additionally, the noncarcinogenic electrophoresis stains such as methylene blue provide inferior visualization for analysis. Even if educators have the resources for including PCR labs into the course curriculum, ambiguous results are a deterrent. Many teachers also are hindered by the expense and time required for PCR reactions, electrophoresis, staining/destaining, and analysis. We have developed curriculum for a PCR simulation to be used in place of authentic PCR in an effort to encourage more widespread use of PCR technology in biology classrooms. The PCR simulation is designed to yield clear and consistent results with minimal manipulations and expense. The simulation was taught side-by-side with a conventional PCR kit marketed to educators. This study was completed in two undergraduate classes at Southern Illinois University Edwardsville and the effectiveness of the simulation in comparison to authentic PCR was determined by analysis of pre and post assessments.

INTRODUCTION

Polymerase chain reaction (PCR) is a technique for amplifying small amounts of DNA that has revolutionized molecular biology. Terrific scientific advances, in disciplines such as genetics, medical science, DNA forensics, and transgenic plant science have been possible using this technology since its development in 1983 (Mullis et al., 1986). Since PCR has had such a profound impact on how scientists study and manipulate DNA it has increasingly been incorporated into secondary and post-secondary science curricula. Previous studies have shown that inquiry teaching can have a positive impact on learning (Rakow, 1986) and PCR provides a valuable tool for inquiry-based learning in molecular biology laboratories. While active learning suggests students are physically participating in the lesson, inquiry learning requires that students are also mentally participating in it. The mental participation is more important than the physical participation in imparting lasting understanding (Lord and Orkwiszewski, 2006). An inquiry PCR lesson would require students to actively explore the lesson questions and objectives, manipulate the PCR reaction components, and make predictions based on their experimental results. The precise nature of PCR, however, can make it challenging in the inexperienced hands of students. The large number of steps involved, lack of proper sterile technique, and

inexperience at micropipetting make this technology cumbersome and unreliable in science classrooms. Additionally, nontoxic, noncarcinogenic, and inexpensive components are preferred for undergraduate science laboratories and necessary in secondary schools. PCR products are typically visualized following gel electrophoresis with the mutagenic stain ethidium bromide. Methylene blue is an alternative DNA stain that is noncarcinogenic but results in inferior staining and often requires more time for staining and destaining (Herrin and Schmidt, 1988). The equipment and various components necessary for authentic PCR are expensive. For example, programmable thermal cyclers for authentic PCR can cost $2000-$4000 for a basic unit.

Even when teachers have the financial resources and equipment to include PCR in their lessons, ambiguous results can be a major deterrent. While authentic PCR is considered quick among research scientists, it requires more time than is available in most classroom laboratory sessions. The time required for PCR reactions, gel electrophoresis, gel staining/destaining, and analysis can deter interested teachers.

In an effort to encourage more widespread inclusion of PCR in biology lab courses, we developed a curriculum for a realistic PCR wet-lab simulation to be used in the place of authentic PCR. The PCR simulation yields clear and consistent results with minimal manipulations and minimal expense. Our objectives are to teach the same lesson as authentic PCR while removing the potential for errors and ambiguous results, reducing cost, reducing teacher preparation time, reducing class time, and making PCR more accessible to biology educators.

MATERIALS AND METHODS

Authentic PCR and the PCR simulation were taught side-by-side in two separate classes over two days at Southern Illinois University Edwardsville. One class consisted of 14 students majoring in secondary science, some of whom had previous experience with PCR. The other class consisted of 11 students majoring in elementary education, none of whom had previous PCR experience. Groups of 3-4 students were randomly assigned to either the authentic PCR lesson or the PCR simulation in each class.

Participating students completed a pre-test to assess their prior knowledge of the subject matter and to self-rate their motivation as students (Figure 1). The pre-test consisted of a nine item Likert-like personal assessment, 12 multiple choice questions, and three short answer questions. After completing the pre-test, all students received a handout containing general information about PCR, a laboratory protocol, and questions for discussion. Figure 2 shows the complete handout received by groups performing the simulated PCR and Figure 3 is the laboratory protocol used by groups performing authentic PCR. We designed the laboratory protocol for the PCR simulation to resemble the authentic PCR protocol; consequently, students were not aware that there were two different curricula performed simultaneously in the classes.

The authentic PCR groups used components from the BioRad Biotechnology Explorer: Genetically Modified Organism (GMO) Investigator Kit (Mardigan and Wiseman, 2007). The GMO Investigator Kit includes reagents and instructions for extracting DNA from three sources; certified non-GMO seeds, known GMO seeds, and a test food of unknown

GMO status. However, we performed the DNA extractions in advance due to time constraints and we used non-GMO frozen corn as the test food. PCR amplified sequences for this exercise were from the 35S promoter of the cauliflower mosaic virus (CaMV 35S) and the Photosystem II chloroplast gene (PSII). CaMV 35S is a promoter commonly used in GMOs and the PSII was included to test for successful DNA extraction from plant material. PCR primers for CaMV 35S and PSII were mixed individually with the three DNA samples (GMO+ DNA, GMO- DNA, test food DNA) for a total of six PCR reactions per group (Figure 4). PCR reactions were completed according to manufacturer's recommendations. The students were able to visualize the presence or note the absence of the amplified DNA by agarose gel electrophoresis (Figure 5). Students determined whether the DNA extractions were reliable by the presence of a 455 bp PSII band in lanes 1, 3, and 5. They also determined whether or not the test food was derived from a GMO crop by the presence or absence of the 200 bp CaMV 35S band in lane 4.

Our curriculum for the simulated PCR wet lab was based on the BioRad Biotechnology Explorer: Genetically Modified Organism (GMO) Investigator Kit model (Mardigan and Wiseman, 2007). The students used the same laboratory techniques and equipment, were asked the same questions, and went through the same inquiry/discovery process as in the authentic PCR laboratory. The simulation included the same six-sample format as the BioRad Kit. However, the initial six sample tubes contained 20 µl of water or plasmid DNA (0.5 µg/µl) instead of extracted genomic DNA (Figure 4). The plasmids pUC18 (2.7 kb) and Mp18 (7.3 kb) were used because they resembled the size relationship of the CaMV35S (200 bp) and the PSII (455 bp) PCR products of the authentic PCR lesson as visualized on an agarose gel (Figure 5). These plasmids are also readily available (Fisher Scientific, USA) and inexpensive. Sample tubes 1, 3, and 5, corresponding to wells 1, 3, and 5 on the gel, contained Mp18 plasmid DNA. Sample tube 6, corresponding to well 6, contained pUC18 plasmid DNA. Sample tubes 2 and 4, corresponding to wells 2 and 4 on the gel, contained 20 µl of water. Note that if the "test food" was to be represented as GMO positive, pUC18 plasmid DNA would be added to tube 4 instead of water .

Each group received a tube of "plant master mix" and a tube of "GMO master mix" to add to the DNA sample tubes. In the BioRad GMO Investigator Kit these tubes contained the components necessary for traditional PCR (Taq polymerase, primers, dNTPs, and buffer). The only difference between the master mixes was the primers. The "plant master mix" contained primers for amplifying the PSII gene fragment and the "GMO master mix" contained primers for amplifying the CaMV 35S fragment. The master mix tubes for the simulation kits contained 20µl of distilled water. Five µl of the "plant master mix" was micropipetted into tubes 1, 3, and 5 and five µl of the "GMO master mix" was added to tubes 2, 4, and 6.

The samples of the authentic PCR groups and the simulated PCR groups were cycled in the thermal cycler as follows: one two minute denaturation cycle at 94°C followed by 35 cycles of amplification that consisted of one minute of denaturation at 94°C, one minute annealing at 59°C, and two minutes extension at 72°C. Lastly, there was a ten minute final extension at 72°C.

PCR products were visualized using electrophoresis on 1% agarose gels. Five μl of loading dye was added to each sample prior to loading the gel and gels were electrophoresed

for 20-30 minutes at 120 volts. Gels were then left in a 1x solution Fast Blast DNA Stain (Bio-Rad Laboratories, Hercules, CA) at 4°C for 48 hours until the next class meeting. Students examined the stained gels and noted the DNA bands in each sample to determine whether or not the test food contained GMOs.

Students completed the questions accompanying the lab handout (Figure 2) after completing all lab procedures. At the next class meeting, two days later, students were given the post-test to assess comprehension and short-term retention of the lesson. Results for authentic PCR and simulated PCR were analyzed by comparing the pre- and post-test results using two-tailed, paired t-tests.

RESULTS

Students in the simulation groups showed significant improvement ($P<0.001$) from a pre-test mean score (± SE) of 40.5 ± 6.3% to a post-test mean score of 62.4 ± 5.6%. Students in authentic PCR group also showed significant improvement ($P<0.001$) from a pre-test mean of 40.6 ± 7.8% to a post test mean score of 65.5 ± 5.5%. The two groups improved, by 21.9 ± 6.1% and 24.8 ± 7.9% respectively, but there is no statistical difference in learning between teaching methods ($P=0.608$).

Science majors and nonscience majors rated themselves in two main areas before participating in the exercise: motivation as a student and prior knowledge of PCR. On a 1-5 scale, the mean motivation ratings were 4.5 for science majors and 4.0 for nonscience majors. The mean ratings for prior knowledge of PCR was 4.9 for science majors and 3.4 for nonscience majors. Given their ratings, we decided to analyze for any differences in learning between the science majors and the non-science majors. Science majors ($n=14$) showed significant improvement from a pre-test mean score of 45.7 ± 6.0% to a post-test mean score of 69.5 ± 5.0%. The nonscience majors ($n=11$) showed significant improvement from a pre-test mean score of 33.9 ± 9.3% to a post-test mean score of 55.8 ± 7.9%. While the average pre-test and post-test scores were higher for science majors compared to the nonscience majors, there amount of improvement (23.8 ± 5.3% and 21.8 ± 8.7% respectively) did not differ ($P=0.757$).

DISCUSSION

We have demonstrated that college students performing a simulated PCR lab showed equivalent academic gains as students performing a comparable authentic PCR lab. Additionally, science majors and nonmajors using the simulation had equivalent gains as majors and nonmajors performing authentic PCR. Incorporating the simulated PCR lesson, however, yields many benefits beyond student success. These benefits include time and money savings as well as ease of implementation for both the teacher and students. Teacher preparation time is drastically reduced from 7-8 hours with the conventional kit, to 2-3 hours with the simulation. In fact, multiple uses of the simulation take much less time to prepare since the teacher can aliquot samples for several labs at one time and store them in the freezer. Teacher preparation for the authentic PCR lesson includes thawing the master mix and primers within 30 minutes of use, an extremely difficult task for teachers with back to back laboratory sections. Warming can denature key components and timing/handling is critical to successful DNA amplification. These are not

considerations for the simulation since the reaction components are replaced with water. Simulated PCR also reduces classroom time since it does not require DNA amplification. In this investigation, students used authentic PCR and simulated PCR in the same laboratory, at the same time, which necessitated running through thermal cycles for the groups doing authentic PCR. If the simulation is taught alone, the time in the thermal cycler could be greatly reduced, or even omitted, since amplification is not necessary for visual results. Teaching what the thermal cycler does is crucial to teaching PCR, even if it is not used in the classroom for the simulation. An option for teachers without access to a thermal cycler is to use water baths with a reduced number of cycles and reduced time at each temperature to simulate the temperature cycling that takes place in authentic PCR.

Cost is also an important factor when considering labs to be included in laboratory courses. The BioRad GMO Investigator Kit costs approximately $25.00 per group, while the simulated PCR lesson costs approximately $6.00 per group. The cost of simulated PCR could be reduced even further for teachers who have the personal or departmental expertise to purify plasmid DNA themselves instead of purchasing plasmid DNA. This cost difference could make teaching the PCR simulation feasible for teachers with small, fixed, annual budgets.

Molecular biology concepts and laboratory techniques are increasingly being taught in high school biology courses (Stiller and Coggins, 2006). The time and financial benefits of simulated PCR over authentic PCR may encourage more teachers to incorporate lab experiences into the high school curriculum. Giving high school biology students an introduction to proper laboratory techniques and molecular biology procedures such as PCR sets them up for potentially greater success in their post-secondary academic science careers (Fernandez-Novell et al., 2002). Overall, simulated PCR lessons promise to be useful tools in post-secondary and secondary biology laboratories.

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Figure 1. Pre-test and post-test administered to all student participants prior to beginning the PCR lesson and two days after completion of the lesson.

Please circle the best answer for the questions below.

1. What is DNA?
   a) an organism's genetic material
   b) an organism's desmosomic material
   c) a product of translation
   d) all of the above

2. A specific sequence of nucleotides in DNA, the functional unit of inheritance, is known as a(n)
   a) ELISA
   b) gene
   c) GMO
   d) intron

3. What does the acronym PCR stand for?
   a) Polymerase Chain Reagents
   b) Polysaccharide Chelation Reaction
   c) Polymerase Chain Reaction
   d) Polysaccharide Chelation Reagents

4. PCR products are composed of _____.
   a) DNA
   b) RNA
   c) both a & b
   d) none of the above

5. What is a transgenic organism?
   a) an organism that has one or more genes from another organism incorporated into its DNA
   b) an organism that has not had any foreign genes incorporated into its DNA
   c) a genetically modified organism
   d) both a & c

6. Choose the ranking from most stable to least stable over long periods of time?
   a) RNA, DNA, protein
   b) DNA, RNA, protein
   c) protein, RNA, DNA
   d) DNA, protein, RNA

7. How many template strands of genetic material must be present for PCR to be successful?
   a) 1000
   b) 100
   c) 1

8. How can you test food to find out if it contains material derived from a genetically modified organism (GMO)?
   a) UV light
   b) PCR
   c) scanning electron microscopy
   d) both b & c
   e) all of the above

9. Which of the following is **NOT** a necessary component(s) of PCR?
   a) polymerase
   b) calcium
   c) nucleotides
   d) primers
   e) magnesium

10. What type of molecule is polymerase?
   a) polysaccharide
   b) nucleic acid
   c) protein
   d) carbohydrate

11. Primers are _____
   a) single stranded
   b) double stranded
   c) necessary for polymerase function
   d) a & c
   e) b & c

12. What is the purpose of the 72 degree incubation step in PCR?
   a) DNA strands are denatured
   b) optimal temperature for polymerase
   c) primers bind to single stranded DNA
   d) all of the above
   e) none of the above

13. Illustrate the banding pattern in an electrophoresis gel for a sample containing 3 DNA molecules of the following sizes: 8000 bp, 4000 bp, and 2000 bp. Explain your reasoning.

14. What is the purpose of including experimental controls?

15. Many foods containing genetically modified crops are highly processed. How might genetic material from whole plants differ from that of processed foods?

Figure 2. Laboratory handout for the simulated PCR. The handout contains general information about PCR and GMOs, the laboratory protocol, and questions for discussion.

PCR FOR INVESTIGATING GMOS IN THE LABORATORY

Adapted from BioRad Biotechnology Explorer GMO Investigator Kit #166-2500EDU

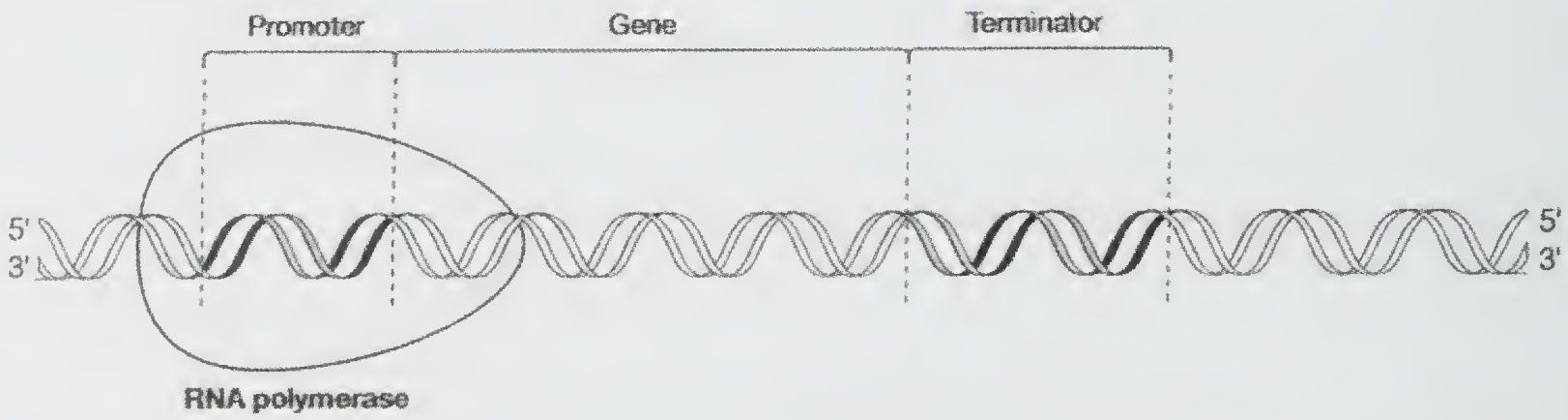
INTRODUCTION

In this lab you will use PCR to test plant extracts. Are the plants or plant products you test from genetically modified organisms (GMOs)?

What are GMOs / GM crops?

Genetically modified crops have had DNA from another organism incorporated into its DNA. The foreign genetic material usually codes for proteins that gives the plants an advantage over non-GMO plants. Examples of traits created via genetic modification include pest resistance, improved fruit yield, herbicide resistance, and increased nutritional content.

For inserting foreign genetic material to work, the host plant's cells must be able to 'read' the information so that transcription is successful. This is done by adding a promoter and a terminator.



Using promoters and terminators, scientists have engineered GMOs so that the foreign gene is continually transcribed allowing the protein to be produced throughout the plant.

What are you looking for?

You will use PCR to test for the presence of the most commonly used promoters and terminators for creating plant GMOs. Since you are testing extracts of plant material and plant products, you will also be testing for the presence of plant material. Presence of the plant protein will signify successful DNA extraction from the initial product (frozen corn, corn chips, flour, soybeans, etc.).

PCR

Remember, each cycle of PCR involves three basic steps:

1. Denaturation (high temperature, 94°C)
2. Primers anneal (low temperature, 59°C)
3. Synthesis (intermediate temperature, 72°C)

Since PCR can produce large quantities of DNA from very small amounts of starting material, contamination with unwanted DNA can be a problem. Be careful to prevent cross-contamination of samples. ***Always use a new pipet tip, keep tubes tightly capped while not in use, and wear clean gloves.***

The PCR reactions will take place in a thermal cycler (PCR machine) that performs the necessary cycles of heating and cooling. The thermal cycler will be programmed to run 35 cycles.

What will you test?
You will use the following control DNA samples:
GMO positive, GMO negative, and plant positive
DNA extractions have been prepared for you ahead of time to use as unknowns.

LAB PROCEDURES

Day One: Set up PCR Reactions

1. Number 6 PCR tubes 1-6 and label with your initials. The numbers on the tubes correspond to the following tube contents:

1	20µl Non-GMO food control DNA	5 µl Plant master mix (green)
2	20µl Non-GMO food control DNA	5 µl GMO master mix (red)
3	20µl Test food DNA	5 µl Plant master mix (green)
4	20µl Test food DNA	5 µl GMO master mix (red)
5	20µl GMO positive control DNA	5 µl Plant master mix (green)
6	20µl GMO positive control DNA	5 µl GMO master mix (red)

2. Keep the tubes on ice for the remaining steps.

3. Using a new pipet tip each time, add 5 µl of the indicated master mix to each tube. Cap each tube immediately.

4. Using a new pipet tip each time, add 20 µl of the appropriate DNA to each tube as indicated by the table above. Recap tubes. Flick tubes with finger to mix.

5. With instructor's assistance, place the tubes in the thermal cycler.

Preparing for Electrophoresis of PCR Products:
When the thermal cycler is done, you have completed your PCR amplification. However, you must visualize your products to determine what you have amplified. You will use gel electrophoresis to do this. 1% agarose gels have been poured before class and are ready for you to use.

Running the Gel, Electrophoresis

1. Using a new pipet tip each time, add 5 µl loading dye to each sample and mix well. Pulse tubes in centrifuge to bring all liquid to bottom of tube after mixing. Be mindful that tubes are placed in the centrifuge in a balanced manner.

2. Using a new pipet tip each time, load the wells with each sample (30 µl) as indicated below:

1	Sample 1	Non-GMO control w/plant primers
2	Sample 2	Non-GMO control w/GMO primers
3	Sample 3	Test food w/plant primers
4	Sample 4	Test food w/ GMO primers
5	Sample 5	GMO positive DNA w/ plant primers
6	Sample 6	GMO positive DNA w/ GMO primers

3. Run your gel for 20-30 minutes at 120 volts, but be careful not to let the dye front migrate out of the agarose gel.

Staining and Rinsing Your Gel

1. Place your gel in a stain solution provided for you. Your gel will stain over the next 48 hours. The results will be ready for you to analyze at the beginning of the next class period.

ANALYSIS OF RESULTS

Once your gel has been stained and destained you will be able to see how far the DNA molecules have migrated.

Lane	Sample	**Bands?**
1	Sample 1: Non-GMO control w/plant primers	
2	Sample 2: Non-GMO control w/ GMO primers	
3	Sample 3: Test food w/ plant primers	
4	Sample 4: Test food w/ GMO primers	
5	Sample 5: GMO positive control w/ plant primers	
6	Sample 6: GMO positive control w/ GMO primers	

Draw your gel.

QUESTIONS

1. What was your test food?

2. Did you generate the expected bands w/ GMO primers (lane 6 & maybe 4)?

3. Based on Lane 4, is your test food a GMO?

4. Did you generate bands w/ plant primers where expected (lanes 1, 3, & 5)?

5. Are you confident in your results? Why or why not?

6. How do the results of the other five PCR reactions help support (or not) the result for your test food?

7. If you were to repeat this lab what might yield better results?

Figure 3. Laboratory protocol for the authentic PCR. The handout resembles the simulated PCR protocol (Figure 2) with minor variations in pipetting volumes. Variations from the simulated protocol are indicated in bold.

LAB PROCEDURES

Day One: Set up PCR Reactions

1. Number 6 PCR tubes 1-6 and label with your initials. The numbers on the tubes correspond to the following tube contents:

1	20µl Non-GMO food control DNA	**20** µl Plant master mix (green)
2	20µl Non-GMO food control DNA	**20** µl GMO master mix (red)
3	20µl Test food DNA	**20** µl Plant master mix (green)
4	20µl Test food DNA	**20** µl GMO master mix (red)
5	20µl GMO positive control DNA	**20** µl Plant master mix (green)
6	20µl GMO positive control DNA	**20** µl GMO master mix (red)

2. Keep the tubes on ice for the remaining steps.

3. Using a new pipet tip each time, add **20** µl of the indicated master mix to each tube. Cap each tube.

4. Using a new pipet tip each time, add 20 µl of the appropriate DNA to each tube as indicated by the table above. Recap tubes. Flick tubes with finger to mix.

5. With instructor's assistance, place the tubes in the thermal cycler.

PREPARING FOR ELECTROPHORESIS OF PCR PRODUCTS

When the thermal cycler is done, you have completed your PCR amplification. However, you must visualize your products to determine what you have amplified. You will use gel electrophoresis to do this. 1% agarose gels have been poured before class and are ready to use.

RUNNING THE GEL, ELECTROPHORESIS

1. Using a new pipet tip each time, add **10 µl** loading dye to each sample and mix well. Pulse tubes in centrifuge to bring all liquid to bottom of tube after mixing. Be mindful that tubes are placed in the centrifuge in a balanced manner.

2. Using a new pipet tip each time, load the wells with **20 µl** of each sample as indicated below:

1	Sample 1	Non-GMO control w/plant primers
2	Sample 2	Non-GMO control w/GMO primers
3	Sample 3	Test food w/plant primers
4	Sample 4	Test food w/ GMO primers
5	Sample 5	GMO positive DNA w/ plant primers
6	Sample 6	GMO positive DNA w/ GMO primers

3. Run your gel for 20-30 minutes at 100 volts, but be careful not to let the dye front migrate out of the agarose gel.

Figure 4. Depiction of the actual reagents added to the six PCR reaction tubes in for the authentic PCR (4a) and simulated PCR procedures (4b). Figure 4a shows that in authentic PCR, purified genomic DNA was added to the tubes along with Plant Master Mix or GMO Master Mix. The master mixes contained the necessary reagents for PCR amplification (Taq Polymerase, dNTPs, primers, and reaction buffer). Figure 4b shows that plasmid DNA or water was added to the tubes in the simulation protocol. Instead of adding Plant Master Mix or GMO Master Mix to the reaction tubes, the students added water.

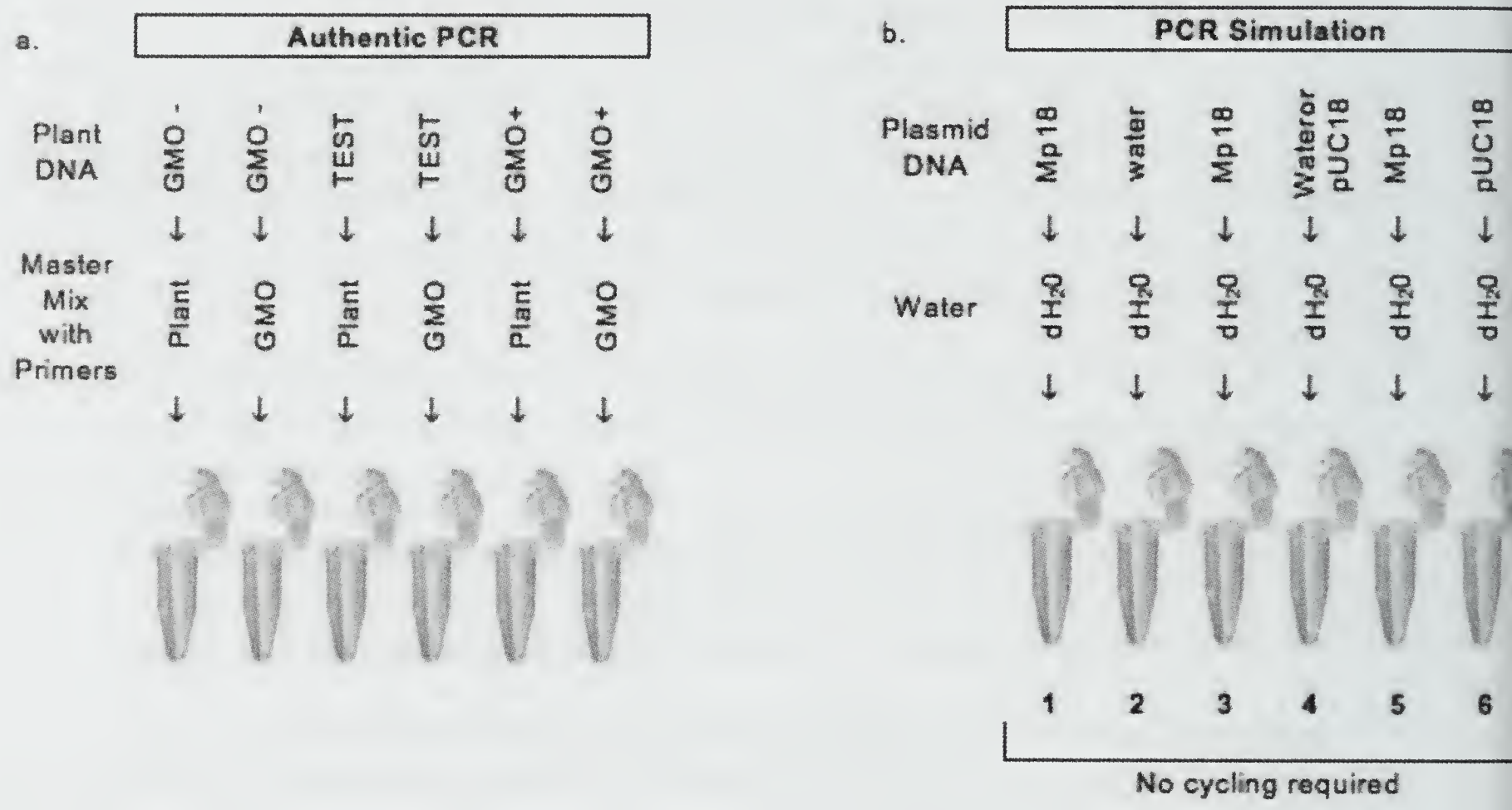
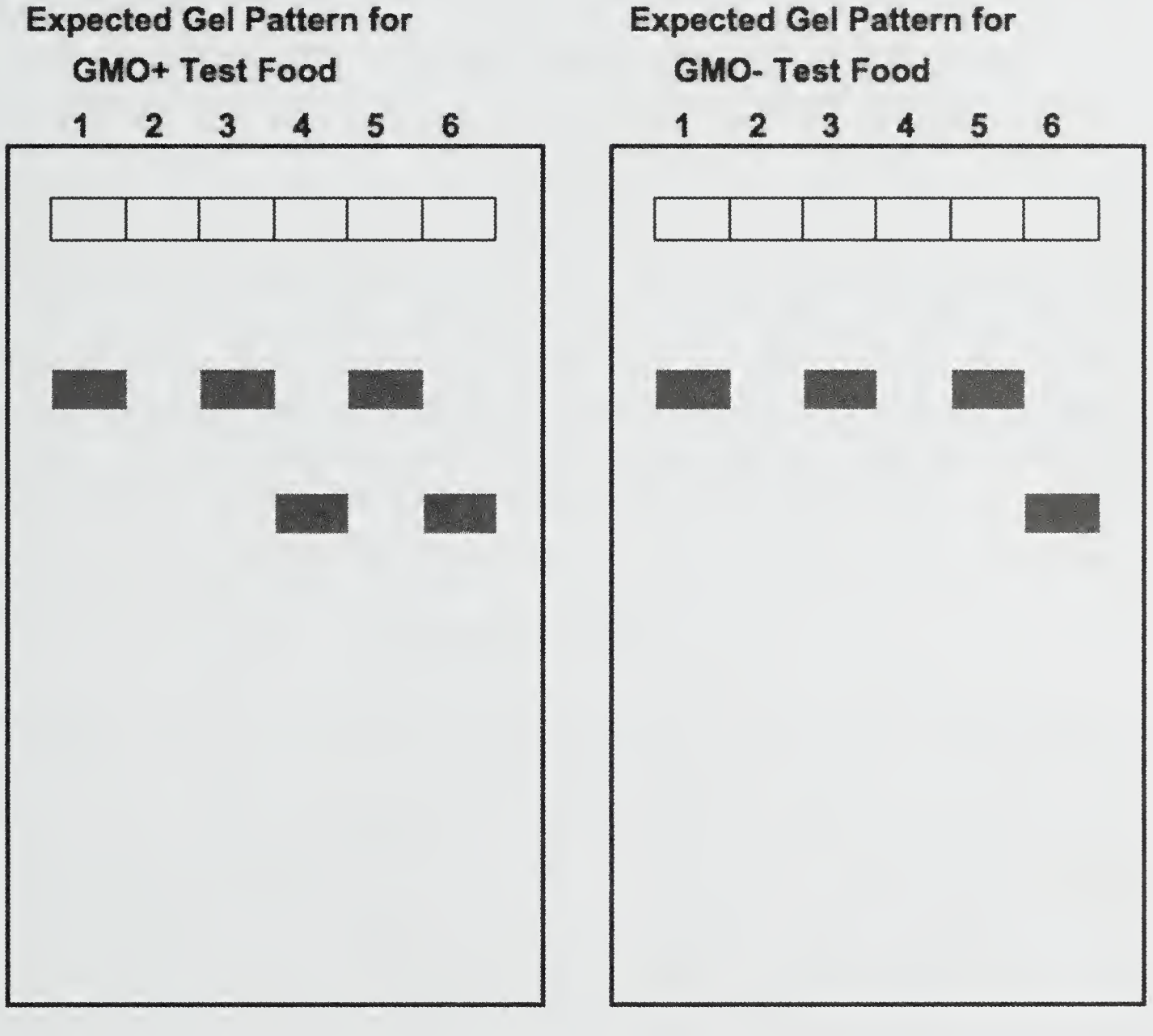


Figure 5. Diagram representing the gel banding pattern obtained for a GMO positive (left) and GMO negative (right) test food. The PCR products from the PSII chloroplast gene (455 bp) in lanes 1, 3, and 5 indicate successful DNA extractions from samples. The PCR reactions from the CaMV35S promoter (lanes 2, 4, and 6) produce a 200 bp band in lane 6 (GMO+), and no band in lane 2 (GMO-). Presence or absence of the product in lane 4 indicates whether or not the test food is from GMO plant material. The bands in the simulation gels follow the same banding pattern.



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Survey for *Macrochelys temminckii* in Southern Illinois: Implications for Recovery Actions

Robert D. Bluett[1], Daniel A. Woolard[2], John G. Palis[3], and Joseph A. Kath[1]
[1]Illinois Department of Natural Resources, Springfield, IL 62702
[2]Illinois Department of Natural Resources, Makanda, IL 62958
[3]Palis Environmental Consulting, P.O. Box 387, Jonesboro, IL 62952

ABSTRACT

Moll's (1988) report to the Illinois Endangered Species Protection Board recommended attempts to locate viable populations of alligator snapping turtles (*Macrochelys temminckii*) before considering management actions. We surveyed 18 sites in southern Illinois and captured 2,671 turtles, none of which were *M. temminckii*. No verifiable records were obtained from our solicitation of observations in two regulatory publications of the Illinois Department of Natural Resources. Our findings are supported by other chelonian studies and a lack of documented records of *M. temminckii* in Illinois during the past quarter century. We conclude recovery of this species is unlikely in Illinois without direct management such as translocation or release of captive-raised individuals.

INTRODUCTION

Alligator snapping turtles (*Macrochelys temminckii*) occur in river systems that drain into the Gulf of Mexico (Ernst et al. 1994). They are distributed widely and locally abundant at the core of their range in Louisiana (Boundy 2003, Boundy and Kennedy 2006), Arkansas (Wagner et al. 1996), Mississippi, southern Alabama (Mount 1975), southwestern Georgia (Jensen and Birkhead 2003) and northwestern Florida (Pritchard 1992). Surveys in Oklahoma (Riedle et al. 2005), Kansas (Shipman et al. 1995) and Missouri (Shipman and Riedle 2008) suggest a reduction of the species' historical range at its northern limits, where alligator snapping turtles are considered absent or limited to remnant populations.

Garman (1892), Cahn (1937), Parmalee (1955) and Smith (1961) noted the species' rarity in Illinois, but considered it endemic to the southern part of the state. Records of its occurrence in Illinois are sparse, with the most recent from 1959, 1960 (Galbreath 1961) and 1984 (Morris and Sweet 1985). Moll's (1988) attempts to determine the species' status by interviewing commercial fishermen along the Wabash, Ohio and Mississippi rivers produced no new records, although 11 of the interviewees recalled seeing specimens in their lifetimes.

Moll (1988) considered his findings inconclusive. Therefore, he recommended that no management actions should take place until surveys occurred in locations most likely to

harbor viable populations. We completed this task prior to implementation of Kath's (2005) recovery plan for the species.

METHODS

Selection of Sites

Moll (1988) identified Mississippi River drainages from Cairo to Grand Tower as the best locations for surveys. Dreslik et al. (1998) believed viable populations might exist in Mississippi River drainages between the Big Muddy and Ohio rivers. Recent (post-1990) records from Indiana (Lodato et al. 1992) and northern Kentucky (Kentucky Natural Heritage Program, Element Occurrence Records, accessed 15 July 2010) add drainages of the Ohio and lower Wabash rivers as possibilities. Targeted surveys failed to detect the species in Indiana (S. Klueh, Indiana Department of Natural Resources, personal communication), so we confined our efforts to drainages of the Mississippi River from Grand Tower, Illinois to the confluence of the Ohio River and drainages of the Ohio River from its confluence with the Mississippi River to Rosiclare, Illinois. Within this area, we chose sites with past records of occurrence and those with suitable habitat based on Kath's (2005) recovery plan or recommendations of biologists familiar with the region (Fig. 1).

Capture Methods

We trapped from April through September, 2005 through 2010, using commercial hoop nets (Memphis Net and Twine Company, Inc., Memphis, Tennessee, USA). Each had a single throat, 3 hoops and 3.81-cm mesh. We baited nets daily with 0.5–1.0 kg of fresh frozen fish. Locations of sets were determined with a hand-held global positioning system (eTrex, Garmin International, Inc., Olathe, KS, USA).

We trapped diverse habitats including streams, rivers, lakes, ponds, swamps and wetlands. Faced with varying depths of water, we chose net sizes best suited to individual conditions so that throats were submerged yet turtles could breathe when captured. Most sets (72%) were made with nets 0.9144-m in diameter, while some employed nets 0.6096-m (18%) or 1.2192-m (10%) in diameter. We checked nets daily and recorded numbers of each species captured. We did not mark individual turtles because our typical protocol of trapping a site for 2–3 nights precluded use of marks to derive robust estimates of abundance. Three authors (RDB, DAW, JAK) captured alligator snapping turtles successfully in Louisiana using methods employed in Illinois, and the fourth was trained by Dr. Paul Shipman, who had conducted surveys in other states.

Observations from Sportsmen

We solicited observations of alligator snapping turtles in two of the Illinois Department of Natural Resources' most widely disseminated publications. Requests occurred in the Digest of Fishing Regulations from 2007 through 2010, and the Digest of Hunting and Trapping Regulations for 2006–07 through 2010–11. Combined annual publication was 775,000–800,000 copies, with online availability at the Department's website.

RESULTS

We expended 377 net nights of effort at 18 sites (Table 1) and recorded 2,671 captures of nine species of turtles (Table 2). No alligator snapping turtles were encountered. We received dozens of reports of alligator snapping turtles from sportsmen and the general public. All except two were discounted as false identifications after further investigation. One report, accompanied by a photograph, was from the Milan Bottoms in Rock Island County. Another, also accompanied by a photograph, originated from Gallatin County.

DISCUSSION

Two observations submitted by the public were the only evidence of *M. temminckii*'s current existence in Illinois. We discounted the specimen reported from Rock Island County because experts (Moll 1988, Dreslik et al. 1998) consider all records originating north of St. Louis, MO as suspect and possibly resulting from releases. We made several attempts to obtain more information about the report from Gallatin County, but the individual who submitted it electronically did not respond to our queries. We do not consider the report from Gallatin County indicative of a viable population because it was isolated and unconfirmed. Alligator snapping turtles are vulnerable to recreational fishing gear (Shipman 1993) allowed in Illinois (i.e., trotlines), so incidental captures are likely sources of observations of this otherwise cryptic species. As Cahn (1937:38) stated, "...such a large animal is more than likely to attract attention if present in any numbers."

Alligator snapping turtles are not difficult to detect where viable populations occur. Surveys using methods similar to ours at similar geographic scales in Oklahoma (Riedle et al. 2005), Missouri (Shipman and Riedle 2008), Louisiana (Boundy and Kennedy 2006), Georgia (Jensen and Birkhead 2003) and Arkansas (Wagner et al. 1996) yielded capture rates of 5.7–23.3 alligator snapping turtles per 100 net nights. Studies of local populations have yielded capture rates as great as 34.9 per 100 net nights (Riedle et al. 2008a). Riedle et al. (2005) considered capture rates of ≥12 alligator snapping turtles per 100 net nights as indicative of viable populations at sites sampled in Oklahoma.

Our findings are supported by other studies in or near Illinois. Scott Ballard of the Illinois Department of Natural Resources sampled for *M. temminckii* in the Mississippi River (Union and Alexander counties), Clear Creek (Alexander County), Heron Pond-Little Black Slough (Johnson County), Loon Lake (Massac County) and Brushy Lake (Massac County); he captured no alligator snapping turtles in 176 net nights of effort (S. Ballard, personal communication). Barko et al. (2004) sampled the Mississippi River from the confluence of the Missouri River (near St. Louis, MO) to the confluence of the Ohio River (near Cairo, IL) to assess commercial fishing gear as a cause of mortality of turtles; they captured no *M. temminckii* in 2,704 net nights of effort. Other relevant studies from Illinois include Readel and Phillips (2008), Palis (2007), Dreslik et al. (2005), Burbrink et al. (1998), Pierce (1992), Klimstra and Hutchison (1965), Minton and Minton (1948) and Cagle (1942); none encountered *M. temminckii*.

The alligator snapping turtle was listed as a state endangered species in Illinois during 1994. Given that recovery is the ultimate goal of listing (520 Illinois Compiled Statutes 10/11), the most salient question is not whether *M. temminckii* exists in Illinois, but

whether it exists in sufficient numbers to fuel a natural recovery. Our findings answer the latter question, especially when considered in the context of other studies. The nearest known viable populations occur in extreme southeastern Missouri (Shipman and Riedle 2008). Therefore, recovery is unlikely in Illinois without supplementing populations as proposed by Kath (2005). Similar programs have been implemented by state agencies in Tennessee (Alan Peterson, Tennessee Wildlife Resources Agency, personal communication) and Oklahoma (Riedle et al. 2008b).

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Table 1. Locations sampled for the presence of *Macrochelys temminckii* in southern Illinois, 2005–2010.

Site	County	Effort (net nights)
Cypress Creek National Wildlife Refuge (Old Channel Unit)	Alexander/Pulaski	17
Horseshoe Lake State Fish & Wildlife Area	Alexander	45
Mill Creek	Alexander/Pulaski	6
Mississippi River	Alexander	26
Big Creek	Hardin	5
Mud Creek	Hardin	4
Big Muddy River	Jackson/Union	34
Tower Island Chute	Jackson/Perry (MO)	21
Mermet Lake State Fish & Wildlife Area	Massac	24
Bay Creek	Pope	18
Big Grand Pierre Creek	Pope	18
Lusk Creek	Pope	37
Sugar Creek	Pope	12
Cache River State Natural Area	Pulaski/Johnson	24
Dutch Creek	Union	24
LaRue Swamp	Union	18
Clear Creek	Union	15
Union County State Fish & Wildlife Area	Union	9
Total effort		377

Table 2. Captures of freshwater turtles during a survey for *Macrochelys temminckii* in southern Illinois, 2005–2010.

	No. captures by species								
Site	*Chelydra serpentina*	*Sternotherus odoratus*	*Chrysemys picta*	*Trachemys scripta*	*Graptemys pseudogeographica*	*Graptemys ouachitensis*	*Graptemys geographica*	*Apalone mutica*	*Apalone spinifera*
Cypress Creek NWR	15	3	2	150	0	0	0	0	1
Horseshoe Lake SFWA	39	1	4	245	0	0	0	0	7
Mill Creek	2	0	0	37	0	0	0	0	1
Mississippi River	25	0	0	357	226	14	0	0	0
Big Creek	4	0	0	11	0	0	0	0	6
Mud Creek	3	2	0	9	0	0	0	0	0
Big Muddy River	23	0	0	519	13	4	1	1	1
Tower Island Chute	0	1	0	164	11	0	0	0	6
Mermet Lake SFWA	36	0	9	137	0	0	0	0	1
Bay Creek	15	0	1	113	0	0	0	0	0
Big Grand Pierre Creek	5	0	0	6	0	0	3	0	1
Lusk Creek	19	4	0	9	0	0	0	0	6
Sugar Creek	3	2	0	23	0	0	0	0	2
Cache River SNA	14	0	2	46	0	0	0	0	1
Dutch Creek	10	0	0	15	0	0	0	0	20
LaRue Swamp	5	6	0	14	0	0	0	0	0
Clear Creek	4	0	0	62	1	0	0	0	12
Union County SFWA	21	2	0	129	0	0	0	0	4
Total	243	21	18	2046	251	18	4	1	69

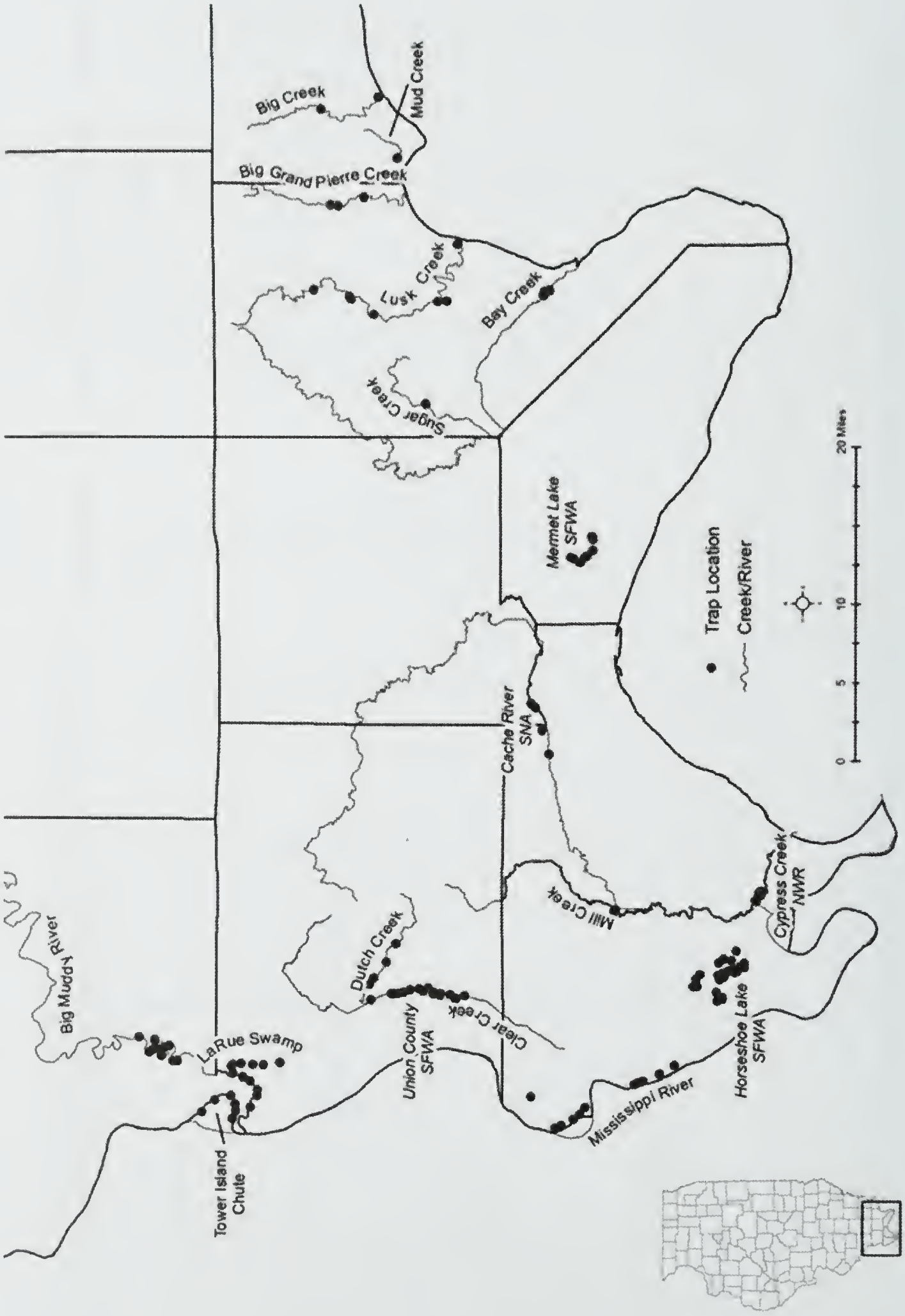

Figure 1. Locations sampled for the presence of *Macrochelys temminckii* in southern Illinois during 2005–2010.

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The Diet of Long-eared Owls (*Asio otus*) in an Urban Park

Dennis A. Meritt Jr., DePaul University, Department of Biological Sciences
2325 North Clifton Avenue, Chicago, IL 60614. dmeritt@depaul.edu

ABSTRACT

Long-eared Owls spent seven weeks in and around an urban park located in Evanston, Illinois. Pellets collected from roosts provide insight to available food resources during the winter of 2008.

Key Words: Long-eared owl, Evanston, Illinois, owl prey.

INTRODUCTION

Long-eared Owls (*Asio otus*) in Illinois are variously described as an uncommon migrant and occasional winter resident (Bohlen, 1989; DeVore et al., 2004; INHS, 2009). In Illinois it is endangered and in adjacent states it is listed as uncommon in Indiana and Wisconsin, of special concern in Missouri and threatened in Iowa (Holt, 1997). Migrant Long-eared Owls have declined in Indiana and Minnesota and are of unknown status in other Midwestern states (Petersen, 1991; Marks et al., 1994). Mlodinow (1989) indicates the period from late November to early April as the best time to see this nocturnal owl species in the Chicago land area. DeVore et al. (2004) cite late October through mid to late April. The unusual appearance of this secretive and shy owl species in a major metropolitan area such as Chicago is a cause for discussion and sharing of observations by ornithologists and bird watchers (IBET, 2008).

Various food items have been identified in the diet of this owl including birds and appropriately sized small mammals (Birkenholz, 1958; Graber, 1962; Maccarone and Janzen, 2005). Pellets or castings are passed once daily, are oval, grayish, measuring approximately 5.0 cm in length and 1.87 cm in diameter (Craighead & Craighead, 1956; Post, 2008). Historically it has generally been accepted that birds appear in Illinois and other Midwestern states in years when there are diminished winter food supplies and/or the onset of severe winter weather in the northern part of their range.

MATERIALS AND METHODS

During the winter of 2007-2008 two Long-eared owls (*Asio otus*) took up residence in a city park (James Park) in Evanston, Illinois. The birds were first noted on 17 January 2008 and last sighted on 29 February 2008. During this time one or both owls could be located during day time hours on most days. Roost trees were identified by significant accumulations of white wash and regurgitated pellets.

Various reports describe roosting location as in groups of conifers near or adjacent to open areas which serve as foraging areas (Burton, J.A. 1973; Marks and Yensen, 1980; Monfils, 2010). In this case daytime roosts were in one of two locations, initially in a dense grouping of red cedar (*Juniperus virginianus*) numbering more than eighteen trees and in late winter in a lone Austrian Pine (*Pinus nigra*). The mean diameter at breast height (DBH) of seven cedars was 24.4 cm (SD = 1.39 cm) and that of the pine 43.75 cm. Both roosts were adjacent to open fields.

On three occasions during March of 2008 owl pellets were collected from underneath roost trees after the birds had departed the area. Earlier pellet collection was hampered by the presence of snow and ice as well as the steepness of the hill at the site. A total of sixty pellets were collected. Pellets were wet weighed immediately after collection and then place in a drying oven at 40 degrees C. Pellets were re-weighed after drying.

RESULTS AND DISCUSSION

During the current observation period, we sampled pellets from under the roosting trees and found mice and voles the predominant prey. After drying, pellets (N=60) were dissected; the type and number of prey per individual pellet was tallied. Voles (*Microtus* sp.) represented one third of the total of prey items (N = 20) and White-footed/Deer Mice (*Peromyscus* sp.) the remaining two-thirds (N = 40). The mean number of prey items per pellet was 1.8 for all pellets combined and varied only slightly between the three collecting dates (1.88; 2.00; 1.70).

Microtus sp. and *Peromyscus* sp. have been identified as common and important prey for this species (Marti, 1976; Cahn, 1930). The present study verifies these earlier reports. The overall ratio of voles to mice consumed at the Evanston site during these observations do not differ significantly from those reported for *Peromyscus* sp. and *Microtus* sp. in a residential area of Urbana, Illinois in 1926-1927 (Cahn, 1930). In that study the ratio was 27% (N = 318) to 56% (N = 673). It is worth noting that the ratio of voles to mice eaten (as judged by pellet analysis) changed from 35% early in the winter to 71% in late winter just prior to owl departure. This could be either an indication of prey availability or a change in feeding pattern from mice to voles just prior to departure. Regrettably it was not possible to independently sample the small mammal population at the site because of location.

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White-tailed Deer Selection of a Travel Route when Dispersing in an Agricultural Environment

Charles M. Nixon[a], Illinois Natural History Survey
1816 S. Oak Street, Champaign, IL 61820
Philip C. Mankin[b], Department of Natural Resources and Environmental Sciences
University of Illinois, 1101 W. Peabody, Urbana, IL 61801
Corresponding author: Charles M. Nixon
Current addresses:
[a]19 Westwood, Monticello, IL 61856; email: cenixon@mchsi.com
[b]5 Steele A Way, Brooksville, Maine 04617

ABSTRACT

Both sexes of white-tailed deer (*Odocoileus virginianus*) traveled about twice as far before selecting a new home range when dispersing through agricultural fields compared to travel through a forested corridor. Travel (km/day) was somewhat greater through agricultural fields, but selection of a travel route did not significantly affect survival or permanent cover selected on the new home range. Corn planting dates and maturation did not influence the timing of a dispersal movement. Selection of a travel route was influenced by the location on the natal range (whether on the edge or center of the area), mother's movements, and the social position of the family group. Subsequent survival after reaching the new home range was dependent more upon hunting pressures on the new range, a factor not readily apparent in late spring-early summer when most dispersal behavior occurs in Illinois.

INTRODUCTION

In Illinois and elsewhere in the lower Midwest, white-tailed deer live in a mosaic of habitats dominated by agricultural fields. Agricultural uses dominate the landscape in much of central and northern Illinois with permanent cover relegated to isolated patches along rivers and streams, hedgerows, or small woodlots (Iverson et al. 1989). More than 50% of the state is devoid of year-round cover for deer (Roseberry and Wolf 1998).

Dispersal behavior (a one-way movement from a natal range to a new range greater than 5 km away) is common for both sexes in the lower Midwest (Nixon et al. 1991, Vercauteren and Hygnstrom 1994). Deer dispersing in late spring in central and northern Illinois have two choices as to a travel route, either to remain entirely within a forest dominated landscape located primarily as corridors along rivers and streams or to travel through agricultural fields largely devoid of cover prior to corn maturation. Landscape structure often influences dispersal distance among vertebrates, and searching for a suitable home range might be more difficult within an agriculture dominated matrix (South et al. 2002, Bowler and Benton, 2005). Intuitively, deer remaining within forest dominated land-

scapes would be more likely to settle within an area offering more permanent cover and protection from hunters and vehicles. In contrast, agriculture dominated landscapes are usually privately owned farms where hunting is encouraged, woodland patches are often small and isolated, and human intrusions into the landscape are frequent. This paper attempts to determine what environmental or social factors affect the selection of a travel route and the costs in inclusive fitness to the individual deer, if any, as a result of this decision.

STUDY AREAS

We used 2 study areas to investigate the selection of a travel route during a dispersal movement (Fig. 1). The 2,953-ha Piatt study area lies within Piatt County in east-central Illinois, which was nearly covered with tall grass prairie prior to settlement by Europeans. In 1985, Piatt county was 2.7% forested, with forests restricted to areas too rough or wet to farm (Iverson et al. 1989). The Piatt study area consisted of 64% row crops (corn [*Zea maize*] and soybeans [*Glycine max*]) and 36% forest and included the 600-ha Robert Allerton Park, a refuge from all hunting. The area was bisected by the Sangamon River with narrow upland and bottomland forests stretching NE–SW across and beyond the study area (Fig. 1). Except for an occasional hedge row, usually only a single tree in width, there was no woody cover for 8–11 km north and south of this study area.

The 1,648-ha DeKalb study area, located in DeKalb County in northeast Illinois, and centered on the Shabbona Lake Recreation Area, lay at the headwaters of a tributary of the Fox River and was surrounded with agricultural fields and urban sprawl (Fig. 1). Row crops covered 59% of the area, while 14% was hardwood forest, 7% was reconstructed tall grass prairie, 6% mixed species pine plantations, and 5% savanna. The remaining 9% included a small suburb, a golf course, and a 128-ha lake. There was no permanent cover available for at least 16 km north and west and 10–13 km east of the study area. There was a small woodlot 5 km due south and 2–3 0.5–1.0 ha woodlots SW of the study area. DeKalb County was only 1.6% forested in 1985 (Iverson et al. 1989).

Hardwood forests on both study areas were generally understocked mixtures of previously pastured or cutover hardwoods. Corn and soybeans were planted from April to early June. Soybean harvests began in late September and corn harvest was completed by early November. Most corn fields were disked or chisel-plowed each fall.

METHODS

Deer were captured using rocket-propelled or drop nets (Hawkins et al. 1968) during 1980–1985 (Piatt County) and 1990–1993 (Dekalb County). Fawns were aged on the basis of tooth replacement (Severinghaus 1949). For this paper we only used deer aged as fawns when captured that dispersed between aged 10–14 mos old, ignoring deer that were migrators.

Males (N = 43) were marked with ear streamers or numbered cattle-type plastic ear tags (Y-Tex Corp., Cody, WY) while females (N = 39) were marked with plastic collars bearing reflective numbers. Radio collars (Wildlife Materials, Carbondale, IL; Teleonics, Inc., Mesa, AZ) were placed on 4 of the 43 males and 20 of the 39 females that became

dispersers. Deer were radio-tracked using 2 truck-mounted 8-element yagi antennas aligned in a null configuration. Each radio location was derived from 2–4 bearings taken from fixed locations generally < 400 m apart. Radio marked deer that dispersed were located by truck or aircraft and then periodically radio tracked during a dispersal movement or after settling on a new home range.

Most dispersal travels were nearly straight line movements based on radio locations taken along the route. We used topographic maps depicting these routes to determine the percentage of forest and row crops traversed during travel.

The minimum distance traveled to a permanent home range was measured as a straight line from the capture location to the center of radio locations or observations on the new home range (mean = 4.9 ± 1.4 SE locations/deer) or to a death location if there were no other observation/radio locations. Daily movements (km/day) were available for 10 females and 5 males (4 with radios, 1 male observed frequently) that dispersed through a forested corridor and for 6 females and 2 males (both through observations) using agricultural fields.

Data Analysis

We used a nominal logistic fit with the travel route (agricultural fields vs. forested corridors) as the dependent variable using 82 fawns that dispersed (43 males, 39 females) and provided sufficient data for each variable. Preliminary independent variables considered for analysis included sex of fawns, social group status (dominant or subordinate), natal range location (edge or center of the study area), fawn age when dispersing (mos.), fawn condition (chest girth taken posterior to the posterior edge of the scapular with the legs perpendicular to the spine and hind foot length taken from the calcanium to the tip of the longest hoof), mother's survival status (alive or dead), mother's movements (sedentary–remained on the study area, migratory–leave and return each year, dispersed–permanently left the study area), percent of corn planted, height of corn maturation (cm) at the time of deer dispersal (Annual Weather and Crop Reports, Illinois Department of Agriculture), and direction of travel during dispersal (NE, SE, NW, SW). Because some variables were extremely skewed, only 7 of these variables were adequate for describing travel route selection in the final logistic regression analysis (mother's survival status, fawn age, location of natal range, direction of travel, percent corn planted, height of corn, and travel distance). Means are reported with standard errors.

To develop Akaike's information criterion (AIC^c) adjusted for small sample sizes (Burnham and Anderson 1998), we tested which environmental and social (mother and other relationships) factors may influence the travel route selection (agricultural fields vs. forested corridors). AIC models used categorical and continuous covariates relating to this selection and used 39 deer (21 males, 18 females) for which we had a complete data set for all variables.

Five environmental models were compared using combinations of the variables: percent of permanent cover present on the new home range (using a 256-ha section centered on radio fixes/observations), the percent of the corn crop planted when dispersal began, the average height of corn (cm) on the date each deer began dispersing, the location on the natal range from which each deer began dispersing (actually left the study area), the path

taken by dispersing fawns (across the study area or from the edge of the study area), general habitat in each natal range (forest, prairie, row crops, pasture), and direction of the dispersal movement (NE, SE, SW, NW).

Five mother models were compared using the variables: mother's range (on the edge or centered on each study area), the dominant land use present on the natal range (forest, prairie, row crops, pasture), mother's age, mother's movements after tagging (sedentary, migratory, dispersed), and mother's social position (dominant or subordinate). The mother's social position was developed on an average of 49 ± 6.1 observations of these deer and was based on aggressive encounters won or lost, leadership among related deer, leadership of large groups of deer in winter, duration of location of a stable home range, and movement behavior after tagging.

Four relationship models were compared using the variables: sex of siblings, number of siblings, the movement history of any siblings (sedentary, migratory, or dispersed), mother's survival status (alive or dead when fawn dispersal began), social group size (number of deer in the social group when dispersal began), and known birth progression for each fawn (first born or later).

Models chosen for inference included the 95% likelihood set based on AIC weights (Burnham and Anderson 1998). The best model from each of the 3 model types (environmental models, mother models, and relationship models) was compared with each other to determine the overall best model. We then used analysis of variance and Chi-square likelihood ratio tests ($\alpha = 0.10$) (Sokal and Rohlf 1995) to examine how sexes might differ in the importance of variables within each model.

RESULTS

Deer that used agricultural fields for dispersal traveled significantly farther before settling on a new range compared with deer using forested corridors to disperse. Females using agricultural fields traveled 48.3 ± 3.6 km, while those using forested corridors traveled 25.1 ± 4.4 km ($F = 16.5$, df = 1,38, P = 0.0002, N = 39). Males using agricultural fields traveled 54.8 ± 5.2 km, while those using forested corridors traveled 25.8 ± 5.6 km ($F = 14.4$, df = 1,42, $P < 0.0004$, N = 43). Both sexes moved about double the distance over agricultural fields to a final location compared with those who dispersed through forest cover. Ten females averaged 5.3 ± 1.5 km/day moving through a forested corridor and 6 females averaged 7.3 ± 1.9 km/day through agricultural fields (P = 0.42). Six males (4 radio tracked, 2 marked and observed each day) averaged 6.9 ± 1.8 km/day through forest cover and 2 males 9.3 ± 2.9 km/day traveling through agricultural fields (sample sizes too small to test.).

For radio marked deer that used forested corridors as travel routes, the landscape traversed by these deer averaged 80 % ± 1.8 forested habitat for females (N = 5) and 75.8 % ± 5.0 forested for males (N = 3). For females (N = 15) traveling through agricultural fields, row crops dominated averaging 95.1 % ± 1.6 of the terrain. The corridors used by male deer (N = 2) using agricultural fields averaged 95.2 % ± 2.6 row crop fields.

Using the nominal logistic fit allows the use of a larger sample (N = 82), and the 7 variables selected to describe travel route selection in the final regression analysis were collectively significant for affecting selection of a travel route (females—N = 39, X^2 = 33.4, P= 0.0001; males—N = 43, X^2 = 32.2, P = 0.0002). However, a stepwise analysis of these 7 variables did not show any 1 variable as significantly associated with travel route selection.

The AIC models separated out 5 variables influencing route selection with the relationship model providing the best fit (Table 1). For females, only the location of the natal range (edge vs. the center of the study areas) significantly affected route selection as 19 of 23 females whose natal range was on the edge of the study areas dispersed through agricultural fields (X^2 = 5.4, df = 1,36, P = 0.01). For males, there were 2 variables affecting travel cover type selection; (1) the direction of travel: 13 of 21 males moved NE (3 through agricultural fields, 10 through forests) (P = 0.002) and (2) group size: 14 of 21 males from the larger social groups led by dominant females (average 5.1 deer/year vs. 3.2 deer for groups led by subordinates) selected a forested corridor for dispersal travel (P = 0.03).

Mother's movements did not have a significant effect on selection by fawns of a travel route, but this may have been the result of a small sample size. All 4 female fawns of migrating mothers dispersed through agricultural fields. Males were not influenced by their mother's movement to disperse through either landscape type. Selection of permanent cover at the end of a dispersal movement was not significantly different between travel routes for either sex.

Moving farther through agricultural fields did not affect survival for either sex (43 males lived 1.8 yrs using the agriculture fields vs. 1.7 yrs using the forested corridors (P = 0.68); 39 females lived 2.5 yrs using agriculture fields vs. 3.0 yrs using forested corridors (P = 0.74).

If dispersal through agricultural fields is a more risky travel option, impending parturition might force some females to select this travel route. We knew the initial reproductive history for 20 primaparous females. Based on observations before and after reaching the new range, 9 females (5 pregnant) dispersed through a forested corridor while 11 females (9 pregnant) dispersed through agricultural fields (X^2 = 1.6, df = 1,18, P = 0.20). There were 11 weaned fawns known alive 1 October for the 14 breeding dispersing female fawns, but only 3 of these fawns were known alive at 1 year. However, 6 (43%) of the 14 breeders were killed during the fall and as their fawns were unmarked, once orphaned, their fate was unknown.

DISCUSSION

Considering the general landscape of east-central and northern Illinois, dispersing deer seem to be able to find diurnal cover during agricultural field crossings using somewhat longer daily movements. The marked deer from the Piatt study area did not move at random, as more emigration was initiated along the forested river corridor (Fig. 1). However, several dispersing deer then left the river and traveled extensively through agricultural fields. Crop maturation did not appear important in controlling the timing of dispersal as

most dispersals occurred before corn plants were high enough to shelter deer, even when lying down. However, very large fields, common in Illinois, offer diurnal protection by their very size and deer could spend daylight hours in these fields well away from more permanent cover. In eastern South Dakota, deer routinely cross wide expanses of open fields to locate permanent cover (Sparrowe and Springer 1970).

Selection of agricultural fields for dispersal travel was not related to the amount of permanent cover found on the new home range, the survival likelihood of dispersing deer, or survival of fawns produced by these dispersing females at least until 1 October. The inclusive fitness of the dispersing females was not compromised by travel through agriculture fields. Once settled on a new range, the odds of further survival were a product of other factors than cover per se, as deer mortality in Illinois is primarily a result of hunting pressures not apparent when the deer selects a new home range in late spring-summer (Nixon et al. 2001).

Edge-located females were usually part of a subordinate social group on our study areas (Nixon et al. 2010). These young females were subjected to harassment by older residents on our trapping sites and when feeding on agricultural fields surrounding the study areas. Such harassment would also be present during dispersal movements which may account for the long distances traveled by these females when dispersing (Gladfelter 1978, Kernohan et al. 1994, Vercauteren and Hygnstrom 1994, Nixon et al. 2007). Unlike males who can select any site containing conspecifics and who often search out such sites that may offer enhanced breeding opportunities, females must find sites that provide an exclusive parturition site not available on the crowded natal ranges found on our study areas. Because dominant females typically inhabit the preferred permanent cover of contiguous woodlands, harassment by more dominant females toward subordinate fawns is much less likely in agricultural fields and small woodlots. In addition, many small woodlots are vacated in the fall because of hunting or inadequate winter cover and thus available for colonization by less experienced subordinate females (Nixon and Hansen 1992).

Travel direction was undoubtedly biased for males on the Piatt study area because the Sangamon River corridor ran NE–SW, and males often followed the river to a new range. The dominant social groups that produced these dispersing males were located on the most stable home ranges near the center of our study area where more extensive forest cover would have been familiar and attractive as dispersal cover to these males. Familiarity with natal landscapes appears to provide one of the cues for dispersers in selecting a new home range (Stamps 2001, Andressen et al. 2002, Stamps et al. 2009).

Subordinates of both sexes appear more likely to select agricultural fields as a travel route compared with members of a dominant social group. Whether due to harassment by dominants or merely a movement from the nearest edge of permanent cover is not known.

These results confirm the ability of white-tailed deer to adapt to an array of fragmented landscape characteristics. Deer, especially those from subordinate social groups (Nixon et al. 2010), are forced to leave the natal range to find mating or parturition sites. Because so much of the present landscape is dominated by agriculture, use of crop fields for travel becomes a necessity. Use of these fields did not significantly affect survival or fawn recruitment per se as deer settled in landscapes providing adequate cover. Future research

should further examine how the juxtaposition of landscape elements governs travel direction and selection of a final home range.

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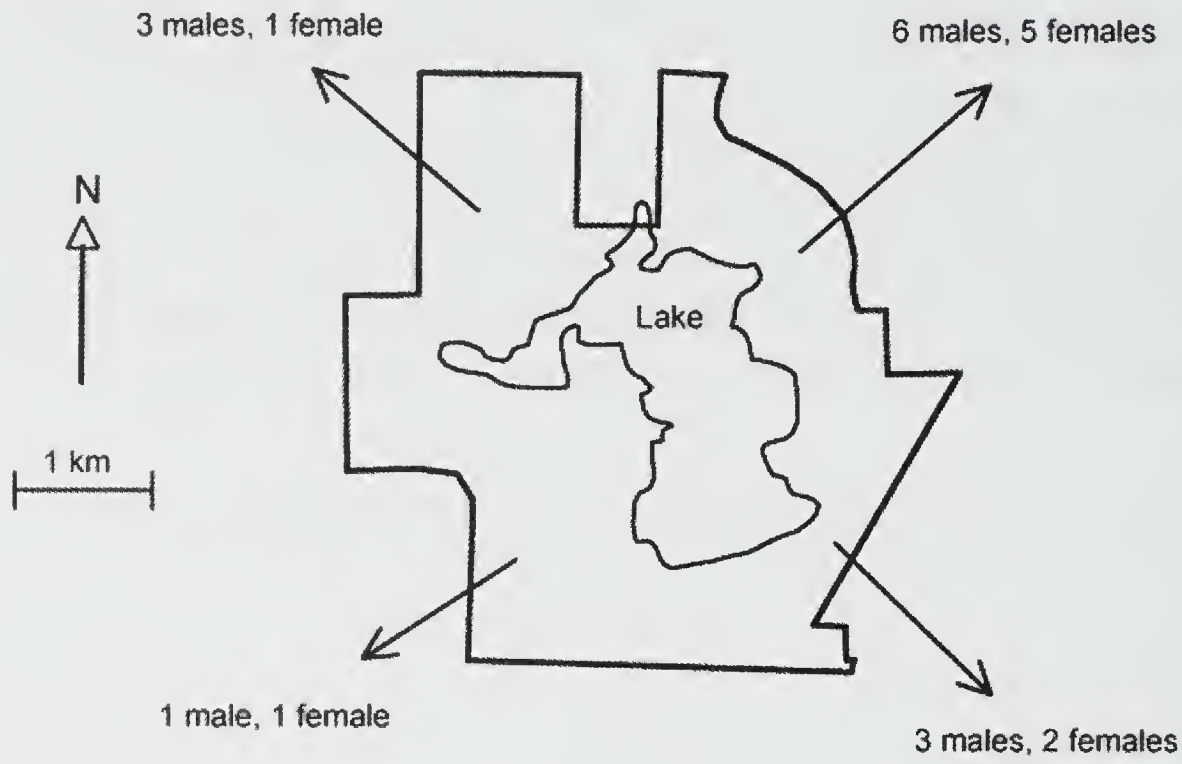
Table 1. White-tailed deer models tested with AIC variables for travel route selection for deer dispersing from sites in northern (DeKalb) and east-central (Piatt) Illinois, 1980–1993.

Model	Variables[a]	N	Log-Likelihood	AICc	DeltaAICc	exp AIC
Environment	%Cover, NR, DT	39	–14.55	40.92	30.19	0.000
Mother	MM, NR	39	–2.46	14.00	3.37	0.185
Relationship	Group size	39	–2.02	10.73	0.00	1.000

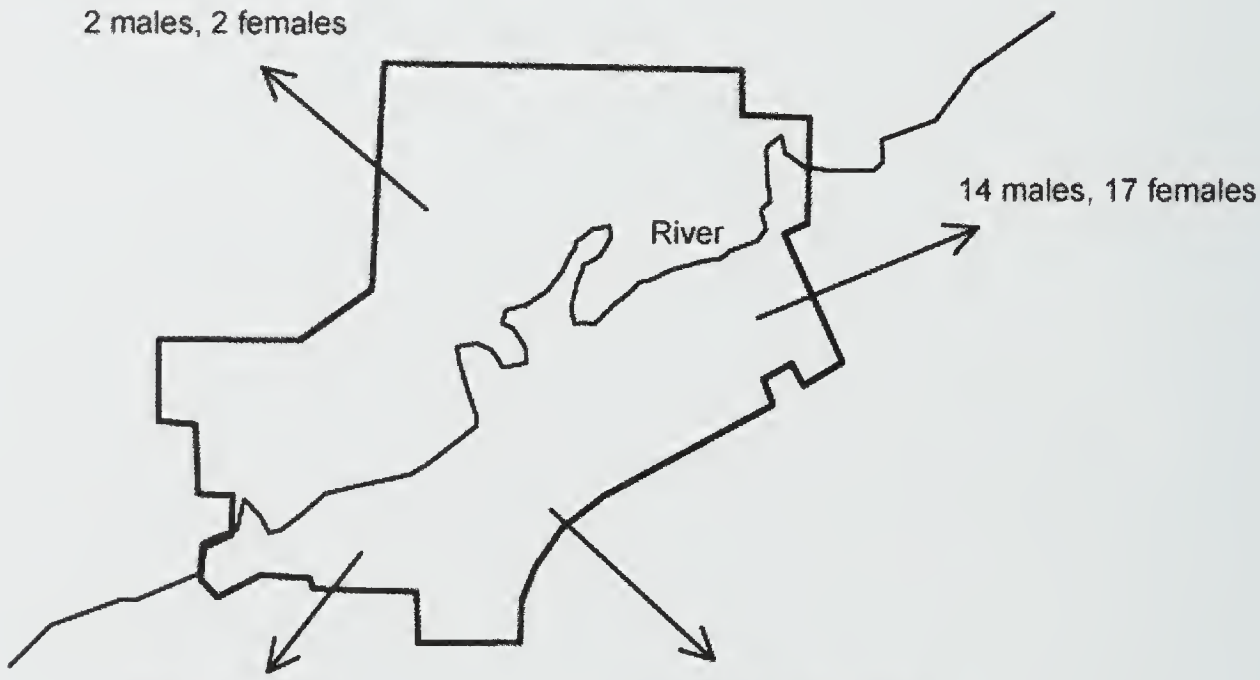
[a] %Cover (percent permanent cover), NR (natal range location—edge or center of a study area), DT (direction of travel—NE, SE, NW, SW), MM (mother's movement—sedentary, migratory, disperse), Group size (number of deer in the social group when dispersal began).

Figure 1. Boundaries of white-tailed deer study areas in northern (A) (DeKalb) and east-central (B) (Piatt) Illinois, 1980–1993. Arrows indicate the direction of initial travel and the number of dispersing male and female deer from both areas.

A) DeKalb Study Area



B) Piatt Study Area



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Insect Emergence Variation in Northern Illinois Wetlands Used by the Yellow-headed Blackbird (*Xanthocephalus xanthocephalus*)

Laura A. Roberts[1], Brenda Molano-Flores[2,3], Michael P. Ward[2], and Daniel C. Elbert[1,2]
[1]University of Illinois, Natural Resources and Environmental Sciences
W-503 Turner Hall, 1102 S. Goodwin, Champaign, Illinois, 61820, USA
[2]Illinois Natural History Survey, 1816 S. Oak Street, Champaign, Illinois, 61820, USA
[3]Author for correspondence

ABSTRACT

In this study, we examined how insect emergence and biomass varied with nest productivity at 13 wetlands in Northern Illinois occupied by Yellow-headed Blackbirds (*Xanthocephalus xanthocephalus*), an endangered species in Illinois, during 2004 and 2005. Insects were collected every 10 days, after which abundance and dry biomass were measured. Significant differences were found for insect emergence between years, but not among wetlands. Overall lower values of insect abundance and biomass were found in 2004 compared to 2005. Year variations were the result of extreme differences in weather conditions, as 2004 was a wet year and 2005 was a dry year. These results suggest that other factors are influencing habitat selection and nest productivity of Yellow-headed Blackbird in these Northern Illinois wetlands.

Keywords: Illinois, insect emergence, Yellow-headed Blackbird, wetland

INTRODUCTION

The Yellow-headed Blackbird (*Xanthocephalus xanthocephalus*) is a neotropical migrant that breeds primarily in western North America with a few small populations scattered east of the Mississippi (Fig. 1, Ward, 2005a). In Illinois, the species is listed as endangered (Ward, 2005a). This large-bodied, polygynous blackbird typically breeds in deep water, emergent wetlands from May to mid-July (Fig. 1, Twedt and Crawford, 1995). In Northern Illinois, Yellow-headed Blackbirds utilize wetlands within a highly urbanized and rapidly developing landscape. Conservation strategies targeting wetland species have been hindered by a lack of information regarding general habitat requirements of birds in urban environments (Enstrom et al., 2000).

Recently, evidence that individuals use information gathered during late-season prospecting to select breeding sites has been reported in Yellow-headed Blackbirds (Ward, 2005b). In this case, sites with relatively high numbers of young produced per female in year$^{(x)}$ best predicted where prospecting adults settled in future years$^{(x+1)}$. Many factors may influence a bird's reproductive success, suggesting that the number of young per

female produced in year$^{(x)}$ integrates many components of breeding habitat quality and make this a particularly informative habitat selection cue for birds in northern Illinois.

How food availability might be associated with Yellow-headed Blackbird nest productivity in an urban landscape is still not well understood. Spatial variation in food abundance is common within habitats (Hutto, 1993), and other work has shown that the number of Yellow-headed Blackbird young fledged at a site correlates with the amount of food there (Orians, 1980; Ward, 2004; Ward, 2005b). The Yellow-headed Blackbird feeds its young primarily odonates, but have also been known to provide trichopteran and dipteran insects (Orians, 1966). In this study we examined insect emergence and biomass in wetlands used by the Yellow-headed Blackbird in Northern Illinois during 2004 and 2005 to examine the degree that these factors were associated with Yellow-headed Blackbird nest productivity. Patterns indicating how insect emergence and biomass affect nest productivity may lead to a greater understanding of habitat selection by the Yellow-headed Blackbird in Northern Illinois and aid in conservation efforts of this species within this region.

METHODS

Study Sites

We studied insect emergence at 13 study sites occupied by Yellow-headed Blackbird in Cook, McHenry, Lake, and DuPage counties in Northern Illinois (Fig. 1) during the breeding seasons of 2004 and 2005. Study sites were selected based on previous records of Yellow-headed Blackbird use, or on the presence of suitable habitat for breeding. Sites with suitable habitat were defined as wetlands with a large area of open water and emergent vegetation capable of supporting nests, such as cattails (*Typha* spp.) and bulrush (*Scirpus* spp.) (Twedt and Crawford, 1995). Study sites were surrounded by an urbanized and rapidly developing landscape. Total precipitation during data collection varied between the two years; 2004 was a wet year (i.e., 30.96 cm. fell from May through July) with some sites flooding and 2005 was a dry year (i.e., 13.84 cm. fell from May through July) with a majority of the sites drying out by the end of the season.

Study sites were differentiated into four groups based on Yellow-headed Blackbird nest productivity in 2004 and 2005 (Table 1). Nest productivity per site, defined as the number of fledged young per nest, was estimated using the ratio of fledglings to adult females observed from mid-May to mid-July. Each site was visited at least four times between sunrise and 10:00AM to determine this ratio. Nest productivity can be determined using this approach due to the conspicuous nature of fledglings and evidence that females in this population are single-brooded (Ward pers. comm.). Because this approach is not as accurate as direct nest monitoring, these data were used to rank sites in 2004 and 2005 using a box plot distribution. Sites ranked 1 or 2 were considered to have high nest productivity and fell within the 25th percentile of the distribution, sites ranked from 3 to 5 were considered to have medium nest productivity and fell within the 50th percentile, sites from 6 to 8 had low nest productivity and fell within the 75th percentile, and sites where nesting did not occur were listed as "no nest productivity" (see site nest productivity rank [SNPR] in Table 1).

Insect Emergence

Insect emergence data were collected for each site from mid-May to mid-July. Three insect emergence traps per site were placed randomly within each wetland at the edge of the emergent vegetation. The traps floated on the water surface with an open area of 30 cm by 30 cm and a cone of mesh extending from the base to a kill jar (Ward, 2005b). Approximately every 10 days insects were collected. Insects were identified to order and Odonata were identified to family (Westfall, 1984; Daly et al., 1998). Insect abundance and dry biomass were determined for these groups (i.e. total insect, odonate, Diptera, damselfly, dragonfly, Lestidae, and Coenagrionidae).

Analysis of variance

Two-way analyses of variance (ANOVA) were used to determine if insect emergence and biomass varied with Yellow-headed Blackbird nest productivity (i.e., site nest productivity rank [SNPR], Table 1]) and year. Log transformations were used to meet ANOVAs' assumptions of normality and/or equal variance (Zar, 1999). All statistical analyses were conducted using Systat 11 (Systat Software Inc., 2004).

RESULTS AND DISCUSSION

Table 1 summarizes all the nest productivity and insect data per site for 2004 and 2005. Number of Yellow-headed Blackbird young per nest ranged from 0 to 2.3 and 1 to 2.8 in 2004 and 2005, respectively. A total of 12,814 insects was collected, with Diptera accounting for 72.5 % of all insects collected in both years. Two-way ANOVAs did not show any significant differences for insect emergence (i.e., abundance and biomass) among SNPR (all F-values < 2.733, all P-values > 0.076), but total number of insects ($DF = 1$, $F = 9.680$, $P = 0.006$), total number of Diptera ($DF = 1$, $F = 10.292$, $P = 0.005$), and Diptera dry mass ($DF = 1$, $F = 6.096$, $P = 0.024$) differed between years with 2004 having lower values than 2005. There were no significant differences for all other insect emergence variables between years (all F-values < 0.695, all P-values > 0.416) or interactions (all F-values < 1.086, all P-values > 0.382).

Although nest productivity and site utilization varied among wetlands examined in this study (Table 1), there was no significant difference in insect emergence and biomass among SNPR. Because insect emergence was not a good predictor of differences in nest productivity among sites, this result further indicates that while nest productivity may be important in the selection of breeding sites in Yellow-headed Blackbirds (Ward, 2005b), insect emergence does not appear to be a critical factor in that process. As mentioned previously, differences in nest productivity among sites may be due to multiple factors other than insect emergence, such as nest depredation or inclement weather (Burger, 1985).

Differences were found between years for total species richness, Diptera species richness and Diptera dry weight; values were higher in 2005 than in 2004. These differences between years can be attributed to extreme variations in overall weather conditions, as 2004 was a wet year and 2005 was a dry year. The lower levels of insect emergence we found in 2004 may be explained by emergence suppression resulting from large amounts of precipitation (MacKenzie and Kaster, 2004). These large amounts of precipitation may also have caused a greater percentage of insects to be washed off of emergence trap walls

in 2004 than in 2005 (Paasivirta et al., 1988). Another possible explanation for differences in insect emergence between years can be high or low water temperatures (Batzer, 1996). However, we believe that this was not a factor in our study because mean water temperatures for the wetlands were similar in 2004 (22.02°C) and 2005 (22.27°C) (data analysis not shown). Lastly, Diptera was the most abundant group of insects in both years (Table 1). High abundance of Diptera in wetlands has been observed in other studies (McLaughlin and Harris, 1990; Ritcher, 2001; Stagliano et al., 1998; Whiles and Goldowitz, 2001). For example, Ritcher (2001) determined that Diptera can make up 99% of the total insect captures.

In addition to maximizing chances for securing a suitable mate, providing shelter for nesting, and protection from weather and predators, breeding habitat must also supply food for raising young (Cody, 1985). However, food availability does not appear to be the mechanism driving this process for Yellow-headed Blackbirds in Northern Illinois. Differences in food availability were not found among the wetland sites we studied in 2004 and 2005 and nestling starvation was rare (Ward, 2004). Previous studies in the same area on Yellow-headed Blackbirds and other wetland birds have found that social factors, such as the number of young produced at a site in a year, may play an important role in the habitat selection process (Ward et al., 2010a). However, most wetland bird populations in northeast Illinois are declining (Ward et al., 2010b), suggesting they may be choosing sites poorly.

It is well documented that in urban areas wetland hydrology is often highly altered and this, coupled with extreme differences in yearly precipitation, may result in situations where insect emergence is highly variable both spatially and temporally. As wetland bird populations decline it becomes imperative that we understand the factors driving insect emergence. While Yellow-headed Blackbirds do not appear to have been food limited, with such a small population in Illinois, a reduction in food availability may be the factor that ultimately extirpates the species from Illinois. More research should be conducted on the role of insect emergence in limiting or promoting wetland bird populations in urban landscapes.

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Fig. 1 The wintering and breeding range of the Yellow-headed Blackbird (*Xanthocephalus xanthocephalus*) in North America, adapted from Twedt and Crawford (1995). Inset picture shows the location of the 13 study sites within the breeding range of the Yellow-headed Blackbird in Northern Illinois (hatch area). This figure is adapted from Ward (2005a).

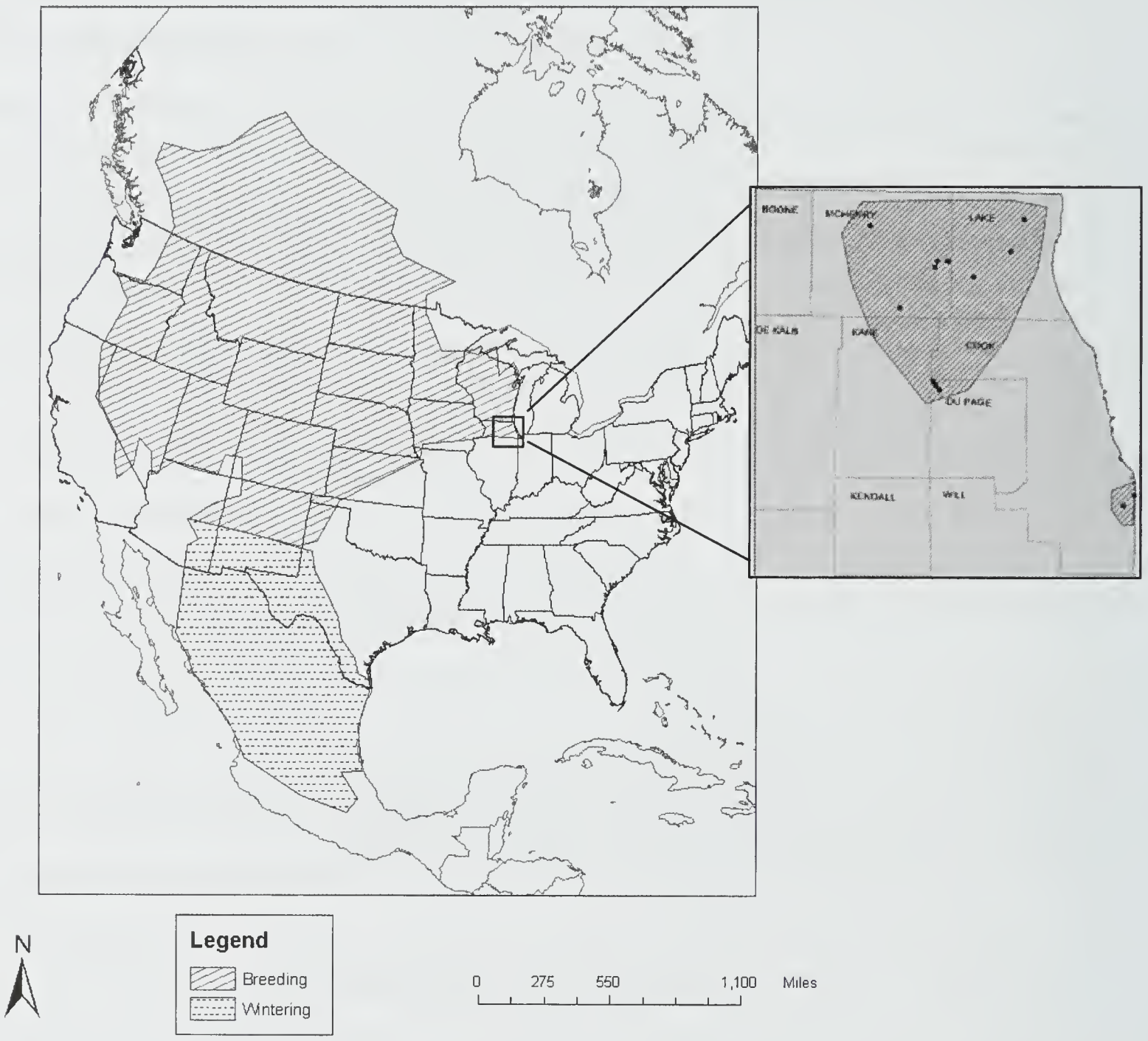

Table 1. Insect emergence data for the 13 northern Illinois wetlands in 2004 and 2005. SNPR = site nest productivity rank, NS = number of young per nest (relative yearly rank), Total = total number of insects, Odo = Odonate, Dip = Diptera, Dams = Damselflies, Drag = Dragonflies, Lest = Lestidae, Coen = Coenagrionidae, W = dry weight (g).

Site name	SNPR	NS	Total	TotalW	Odo	OdoW	Dip	DipW	Dams	DamsW	Drag	DragW	Lest	LestW	Coen	CoenW
2004																
Eggers	High	2.1 (2)	199	0.171	1	0.014	161	0.0505	1	0.014	0	0	0	0	1	0.014
Tony	High	2.3 (1)	535	2.038	60	0.779	239	0.363	55	0.294	10	0.522	1	0.004	54	0.29
Hegewisch	Medium	1.5 (5)	302	0.875	52	0.692	193	0.123	44	0.304	8	0.388	16	0.136	28	0.168
BT	Medium	2.0 (3)	95	0.125	6	0.054	84	0.054	4	0.026	2	0.028	1	0.002	3	0.024
Broberg	Medium	1.9 (4)	170	0.293	15	0.158	102	0.038	11	0.076	5	0.086	11	0.076	0	0
PWI	Low	0.8 (7)	149	0.282	9	0.085	98	0.117	9	0.112	0	0	6	0.076	3	0.036
PWII	Low	1.0 (6)	52	0.091	4	0.041	28	0.032	4	0.041	0	0	1	0.03	3	0.011
Almond	Low	0.0 (8)	336	2.46	152	2.116	129	0.184	145	1.49	7	0.626	2	0.01	143	1.48
BC	None	- (-)	90	0.26	16	0.187	36	0.026	15	0.187	0	0	0	0	15	0.187
Stickney	None	- (-)	315	0.186	9	0.056	245	0.061	9	0.042	0	0	1	0.012	8	0.03
Wadsworth	None	- (-)	802	0.853	25	0.249	692	0.525	25	0.249	0	0	4	0.034	21	0.215
Exner	None	- (-)	165	0.279	4	0.028	141	0.206	4	0.028	0	0	1	0.012	3	0.016
2005																
PWII-A	High	2.0 (2)	195	0.327	24	0.174	129	0.099	24	0.174	0	0	7	0.078	17	0.096
Tony	High	2.8 (1)	920	1.434	115	0.71	630	0.492	115	0.71	0	0	3	0.034	112	0.676
Eggers	Medium	1.8 (4)	829	1.269	52	0.89	674	0.247	35	0.242	17	0.648	10	0.104	25	0.138
PWII	Medium	1.9 (3)	692	1.335	77	0.766	512	0.455	77	0.766	0	0	35	0.496	42	0.27
BT	Medium	1.7 (5)	456	0.575	9	0.143	402	0.387	8	0.025	1	0.118	0	0	8	0.025
Hegewisch	Low	1.5 (6)	820	0.644	16	0.064	698	0.493	32	0.076	0	0	0	0	32	0.076
Broberg	Low	1.0 (7)	1564	1.115	18	0.132	1013	0.674	18	0.132	0	0	9	0.087	9	0.045
PWI	None	- (-)	141	0.157	0	0	101	0.054	0	0	0	0	0	0	0	0
BC	None	- (-)	864	1.423	176	0.84	575	0.492	176	0.84	0	0	0	0	176	0.84
Stickney	None	- (-)	113	0.291	8	0.166	80	0.028	7	0.02	0	0	1	0.008	6	0.012
Almond	None	- (-)	909	1.359	86	0.784	665	0.434	83	0.37	3	0.414	0	0	83	0.37
Wadsworth	None	- (-)	580	0.94	18	0.134	404	0.558	18	0.126	1	0.012	3	0.052	15	0.074
Exner	None	- (-)	1521	1.719	29	0.163	1258	1.419	29	0.163	0	0	0	0	29	0.163

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Feasibility of Public-Private Partnerships for Swamp Rabbit Conservation

Lyann Rubert, Eric M. Schauber*, Clayton K. Nielsen, and Paul D. Scharine
Cooperative Wildlife Research Laboratory and Department of Zoology
Southern Illinois University, Carbondale, IL, USA

*Address Correspondence to: Dr. Eric M. Schauber,
SIUC Cooperative Wildlife Research Laboratory, Mailcode 6504,
Carbondale, IL 62901 USA. Email: schauber@siu.edu

ABSTRACT

The distribution and abundance of swamp rabbits in southern Illinois have decreased due to loss and fragmentation of bottomland hardwood forests. Remaining populations are likely isolated because of limited dispersal across open areas. Private citizens own 69% of highly suitable swamp rabbit habitat in southern Illinois, so public-private partnership is key to any conservation efforts. Owners of highly suitable habitat were sent mail surveys to determine current and acceptable forms of land management, participation in government incentive programs, and interest in swamp rabbit conservation. The response rate was 41%, and 69% of surveyed landowners indicated interest in learning about or participating in swamp rabbit conservation efforts, implying that creation of public-private partnerships could be feasible. Nearly half of the respondents were already enrolled in government incentive programs. Our results suggest that there could be substantial support for swamp rabbit conservation, and that outreach efforts may increase enrollment in incentive programs.

Keywords: Government incentive programs, private land management, public opinion, public-private partnership, swamp rabbit, *Sylvilagus aquaticus*

INTRODUCTION

Conservation on private lands is one of the most pressing challenges in conservation (Knight, 1999; Freyfogle, 2003). Approaches to land conservation in the United States since the late 1880s have typically consisted of government reservation or acquisition of land (Jensen et al., 1993; Press et al. 1996; Raymond and Fairfax, 1999). However, funds are often not available to purchase lands and governments are often constrained in their ability to act quickly and efficiently (Endicott, 1993). Sustained and flexible outside support (financial and consultative) is required for most conservation projects on privately owned lands to be successful (Sinclair et al., 2000).

Conservation easements are voluntary, incentive-based approaches that depend upon continued private ownership and management of land used in conservation, which avoids the financial costs and political difficulties associated with public land acquisition and management (Merenlender et al., 2004). The increasing appeal of conservation easements

has been attributed to rising land values, high cost of government land management, frustration with gridlocked public land-management and resource agencies, and real or perceived insensitivity of federal and state regulatory authorities toward local communities (Turner and Rhylander, 1998). Conservation easements usually cost less than land acquisition (Main et al., 1998), and they may also facilitate various landowner goals (Wright, 1994). Unlike public acquisition, the property stays on the local property tax rolls (although generally at a reduced rate) and in some cases this can improve community support (Merenlender et al., 2004).

The swamp rabbit (*Sylvilagus aquaticus*) is a species that could benefit from cooperative habitat management by public agencies and private landowners. Woolf and Barbour (2002) estimated that 32% of sites occupied by swamp rabbits in southern Illinois were in private ownership and Rubert (2007) found that 79% of highly suitable swamp rabbit habitat in southern Illinois was privately owned. Swamp rabbits are closely associated with bottomland hardwood forests in the southeastern U.S. and along the Mississippi River and its tributaries (Lowe, 1958; Chapman and Feldhamer, 1981; McCollum and Holler, 1994). Large-scale swamp rabbit population decline has been linked to habitat destruction (Terrel, 1972; Korte and Fredrickson, 1977; Whitaker and Abrell, 1986; Kjolhaug and Woolf, 1988; Sole, 1994). Most of the swamp rabbit's historic habitat has been negatively impacted by flood control structures and conversion of forest to agriculture, and bottomland hardwood forests have been designated as a habitat of regional concern (Hunter et al., 1993).

Various government incentive programs can be used by private landowners to improve or create swamp rabbit habitat in southern Illinois. The U.S. Department of Agriculture has several programs directed toward private landowners to encourage wildlife conservation, including the Wetlands Reserve Enhancement Program (WREP) in their Wildlife Habitat Incentives Program (WHIP), Conservation Reserve Program (CRP), and Wetland Reserve Program (WRP). These programs offer easements and incentives for those interested in managing their private lands for the benefit of wildlife. The Illinois Forestry Development Cost Share Program, which reimburses eligible landowners for a portion of their costs for the preparation of forest management plans and practices, is also available.

Although private lands can allow for more flexibility in management options, publicly-owned areas contain most of the largest remaining habitat patches (Woolf and Barbour, 2002) and sites where swamp rabbits are highly abundant (Rubert, 2007). However, the public is generally opposed to burning and logging (Dessecker and McAuley, 2001), and this opposition limits the options for managing swamp rabbit habitat on public lands. The willingness of agencies, such as the IDNR, U.S. Fish and Wildlife Service (USFWS), and the U.S. Forest Service (USFS), to manage for swamp rabbit habitat can vary. Woolf and Barbour (2002) recommended that public and private lands be integrated into a partnership-based swamp rabbit management plan.

Our objective was to assess the feasibility of creating public-private partnerships to benefit swamp rabbit conservation. We sought to identify factors that would predict a landowners' willingness to participate in or learn more about swamp rabbit conservation. We also assessed current private land management practices in areas of highly suitable swamp rabbit habitat.

METHODS

Owners of lands identified as suitable swamp rabbit habitat were asked in 2007 to participate in a written survey to determine current and acceptable forms of land management, participation in government incentive programs, and interest in participating in swamp rabbit conservation efforts (Appendix A). Landowners were also asked whether they reside or hunt on the property and whether they practice agriculture on their property.

To identify owners of swamp rabbit habitat for our survey, a map of suitable habitat (Rubert, 2007; Figure 1) was overlaid onto 1998 1 m^2 ground resolution Digital Orthophoto Quarter Quadrangles for Alexander, Johnson, Massac, Pope, Pulaski, and Union counties using ArcMap (Environmental Systems Research Institute, Redlands, California). Landowners were identified using county plat maps. We visited several counties to collect landowner mailing addresses from county tax assessor offices. Landowners received four mailings based on the Total Design Method (Dillman, 1978). They were initially mailed an introductory letter, questionnaire, and a postage-paid envelope. A second mailing consisted of a postcard reminder thanking them for their cooperation. The third mailing to those that had not yet responded contained a cover letter, replacement questionnaire, and a postage-paid envelope. The final mailing was another postcard reminder, emphasizing the importance of the survey. Some survey respondents were contacted by telephone to clarify unclear responses.

We used single-factor logistic regression (McCullagh and Nelder 1989) in SAS (SAS Institute, Cary, North Carolina) to identify which factors were associated with willingness to participate in swamp rabbit conservation efforts, because willingness was recorded as a binary variable (yes or no). The independent variables we considered were length of ownership, presence of agriculture, presence of pasture, if the respondent had seen a swamp rabbit, if the respondent was currently engaged in any land management practices to benefit wildlife, if hunting or trapping took place on the respondent's land, and if the respondent found any land management practices to be unacceptable. To further clarify and reinforce the logistic regression results, we also conducted a forward stepwise selection procedure ($\alpha = 0.05$) to identify predictors of willingness to participate in conservation efforts

RESULTS

Surveys were sent to 372 landowners, of which 151 responded for a total response rate of 41%. The average (± SD) length of land ownership was 33 ± 26 years. Just over half of landowners reportedly did not reside on their properties, but few resided on their property for only part of the year (Table 1). Most respondents practiced agriculture, with similar numbers growing crops and with pasture (Table 1). The majority of respondents reported managing wildlife and their habitat in some way (Table 1), and the most frequently used technique was planting food plots. Nearly half of respondents were already enrolled in a government incentive program (Table 1). Among these, the CRP was the most popular incentive program, followed by WRP, the Illinois Forestry Development Cost Share Program, WHIP, and "other" (Figure 2). Thirty-eight percent of the enrolled respondents were enrolled in ≥1 program. Few respondents objected to any management techniques (Table 1), but burning and grazing management received some objections. Over two-

thirds of landowners indicated interest in learning more about swamp rabbit conservation (Table 1). A large majority of landowners reported hunting or trapping on their property (Table 1). The species hunted most were deer (*Odocoileus virginianus*), waterfowl, and turkey (*Meleagris gallopavo*); swamp rabbits or eastern cottontails (*Sylvilagus floridanus*) were hunted by 26% of the respondents. Few landowners reported seeing swamp rabbits on their property, but approximately one-third were unsure (Table 1).

In the simple logistic regression model, the only variable that significantly predicted willingness to learn about or participate in swamp rabbit conservation was whether the landowner had seen a swamp rabbit ($\chi^2 = 5.8$, df = 1, $P = 0.02$); not having seen a swamp rabbit had a negative effect on willingness to participate (odds ratio= 0.44). The logistic regression was a good fit according to the Hosmer and Lemeshow Goodness-of-Fit test ($\chi^2 = 10.13$, df = 8, $P = 0.25$). Stepwise variable selection indicated that engaging in wildlife management practices had a positive effect (odds ratio = 1.50) on the respondents' interest in swamp rabbit conservation practices ($\chi^2 = 3.88$, df = 1, $P = 0.05$).

DISCUSSION

None of the variables we examined was a strong predictor of landowner interest in participating in swamp rabbit conservation. We had expected that landowners that already practiced management techniques or that were enrolled in an incentive program would be more amenable to conservation efforts. Whether a respondent reported having seen a swamp rabbit on their property was significant in the logistic regression analysis, and an interesting result because this was probably the least reliable response. Swamp rabbits are cryptic and observations can be rare, even where they are abundant (Chapman and Feldhamer, 1981). Also, swamp rabbits and cottontails can be difficult for an observer to distinguish at a distance.

Our survey results are likely to be affected by nonresponse bias (Groves, 1989; Groves et al., 2002; Lynn, 2003). Characteristics of interviewers and potential respondents (Groves and Couper, 1998), attributes of survey design (Lynn et al., 1998; Edwards et al., 2002), and survey environment (Couper and Groves, 1996) can all affect survey participation. Interviewees that feel a survey is an invasion of privacy (Singer et al., 1993) or that lack interest in a survey (Martin, 1994; Groves et al., 2004) are less likely to return the survey. We received three hostile responses to our survey. Mail surveys typically have a lower response rate than more personal forms of communication, however they are more cost-efficient, give respondents privacy, and do not limit participants' time to think (Mannesto and Loomis, 1991).

Some respondents seemed to have been confused and had to be contacted for further clarification. For example, several respondents appear to have entered acceptable management practices in response to the question about unacceptable practices. Some of the responses might have been different if questions were clearer or better explained. Respondent participation is negatively affected by survey length (Burchell and Marsh, 1992; Bogen, 1996) and the amount of time and effort required to complete the questionnaire (Sharp and Frankel, 1983), which placed restrictions on the quantity of materials that could be sent.

Maintaining viable and well-distributed swamp rabbit populations requires active management to create early-successional areas within established bottomland hardwood forests (Woolf and Barbour, 2002). Active management efforts are expensive and labor intensive, limiting their use. Additionally, managers can face opposition when they attempt to manage for early-successional habitats through logging and burning on public lands, and timber harvest is very limited on public lands in southern Illinois. Therefore, more management options are available on private land than on public land in this region. Through conservation easements, managers can lower land-protection and management costs. Most of the easement contracts include reforestation plans that would create suitable swamp rabbit habitat. Swamp rabbits have been found in reforested areas within five years of planting, because reforested agricultural fields create early-successional forests with thick understory cover preferred by swamp rabbits (Scharine et al., 2011).

Conservation easement funding is limited and expecting immediate enrollment of all landowners whose lands are important to swamp rabbit conservation would be unreasonable. Many landowners that are not enrolled in conservation programs in southern Illinois are already engaged in wildlife management. Through outreach and education programs directed toward non-enrolled landowners, managers can encourage management techniques such as timber harvest, creation of brush piles, and reforestation that would benefit swamp rabbits. We found that a large majority of landowners wanted to learn more about or participate in swamp rabbit conservation efforts, providing reason for optimism that such outreach efforts would be successful.

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APPENDIX A

Please answer the following questions regarding your property in _____ county. The following information is being used for my study regarding habitat connectivity for the swamp rabbit in Southern Illinois. Thank you for your cooperation.

Lyann Rubert, Graduate Research Assistant
Cooperative Wildlife Research Laboratory, Southern Illinois University Carbondale

1) How long have you owned this property?

2) Do you reside on this property?
___Yes ___No
If yes, do you reside there year-round?
___Yes ___No

3) Have you seen swamp rabbits on your property?
___Yes ___No ___Not sure

4) Do you grow agricultural crops on this property?
___Yes ___No
If yes, what do you plant?
___ Soybeans ___Corn ___Milo/Sorghum ___Millet ___Rice___
Other_____

5) Do you have any pasture on this property?
___Yes ___No

6) Do you use any of the following techniques specifically to manage wildlife and its habitat?
___Yes ___No
If yes, check which ones you practice
___Predator control ___ Food plots ___Grazing management
___Prescribed burning ___Plantings ___Reforestation
___Removing exotic species ___Creating brush piles
___Timber harvest ___Managing water levels ___Other_____

7) Do you participate in any of the government incentive programs for conservation listed below?
___Yes ___No
If yes, please check which one(s) you participate in
____Wildlife Habitat Incentives Program (WHIP)
____Conservation Reserve Program (CRP)
____Illinois Forestry Development Cost Share Program
____Wetland Reserve Program (WRP)
____other_____

8) Would you consider any of the management techniques below to be unacceptable for use on this property?
___Yes ___No
If yes, check any unacceptable practices
___Predator control ___ Food plots ___Grazing management
___Prescribed burning ___Plantings ___Reforestation
___Removing exotic species ___Creating brush piles ___Timber harvest
___Managing water levels ___Other_____

9) Would you be willing to find out more about participating in swamp rabbit conservation?
___Yes ___No ___Not sure

10) Do you or others hunt or trap on your property?
___Yes ___No
If yes, which animals are hunted/trapped on your property?
___Waterfowl ___Quail ___Dove ___Turkey ___Deer ___Beaver
___Raccoon ___Mink ___Coyote ___Fox ___Muskrat ___Skunk ___Squirrel
___Rabbit ___Other_____

THANK YOU!

May we contact you about conservation efforts?
___Yes ___No

Please update your contact information.
Name:_____
Address: _____
_____
Phone: _____
E-mail address: _____
Which is the best way to contact you?_____

COMMENTS
_____

Table 1. Responses by southern Illinois landowners to a 2007 survey regarding their land management practices and willingness to participate in swamp rabbit conservation efforts.

Question	Yes	No	Not Sure	% Yes
Do you reside on this property	64	74		47
Have you seen swamp rabbits on your property?	21	70	45	15
Do you grow agricultural crops on this property?	89	47		65
Do you have any pasture on this property?	90	47		66
Do you use any of the following techniques specifically to manage wildlife and its habitat?	86	50		63
Do you participate in any of the government incentive programs for conservation listed below?	64	72		47
Would you consider any of the management techniques below to be unacceptable for use on this property?	47	88		35
Would you be willing to find out more about participating in swamp rabbit conservation?	95	43		69
Do you or others hunt or trap on your property?	110	23		83

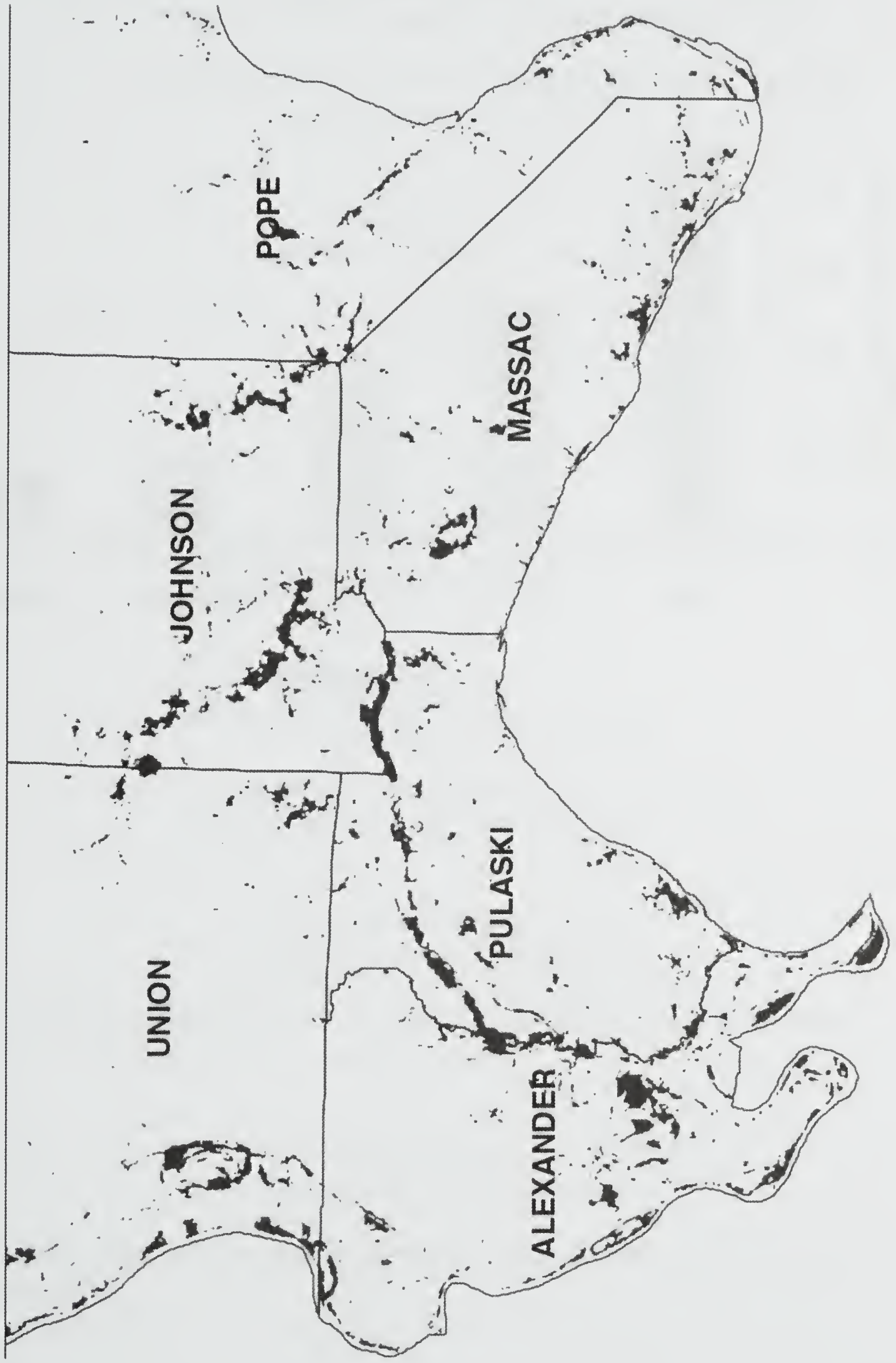
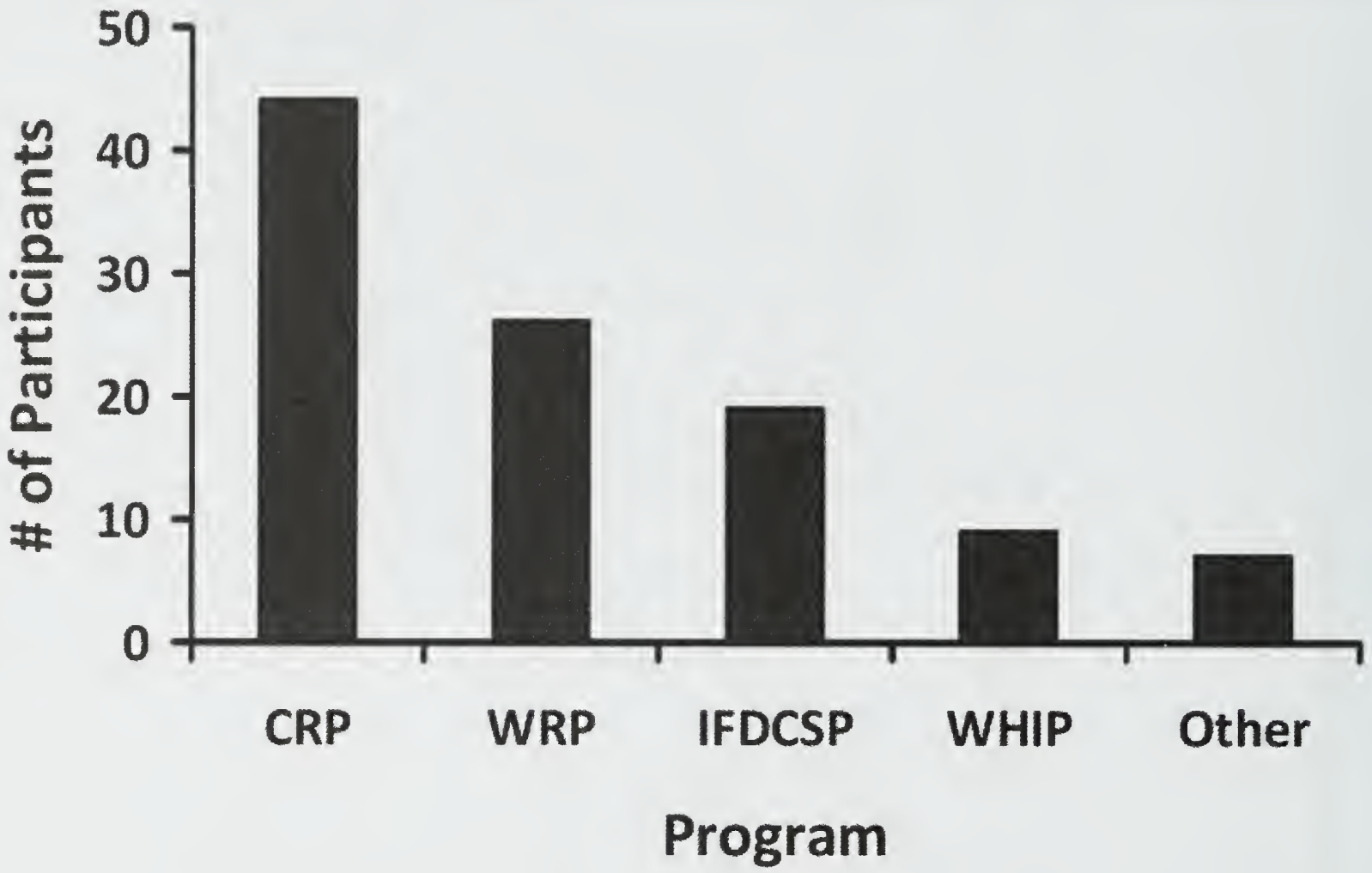


Figure 1. Map of highly suitable habitat for swamp rabbits (dark gray areas) in southern Illinois, based on Rubert (2007).

Figure 2. Reported participation in government incentive programs aimed at conserving wildlife habitat, among southern Illinois landowners surveyed in 2007. Programs include: Conservation Reserve Program (CRP), Wetland Reserve Program (WRP), Illinois Forestry Development Cost Share Program (IFDCSP), Wildlife Habitat Improvement Program (WHIP), or "other."



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Transactions Information

***Transactions* Editor**
Teresa (Tere) North
Western Illinois University
teren1956@gmail.com

Executive Secretary
Robyn Meyers
Illinois State Museum
rmyers@museum.state.il.us

DIVISION CHAIRS

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crwatson@millikin.edu

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Southern Illinois University Edwardsville
kbarry@siue.edu

Zoology
David Duvernell
Southern Illinois University Edwardsville
dduvern@siue.edu
Paul Brunkow
Southern Illinois University Edwardsville
pbrunko@siu.edu

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A Review of the Genus *Scleria* (Cyperaceae) in Illinois

Gordon C. Tucker[1] and John E. Ebinger[1,2]
[1]Department of Biological Sciences, Eastern Illinois University, Charleston, IL 61920
[2]Illinois Natural History Survey, 1816 South Oak St., Champaign, IL 61820
e-mail: gctucker@eiu.edu; jeebinger@eiu.edu

ABSTRACT

Presently, five taxa of *Scleria* (nut rush, Cyperaceae) have been reported for Illinois [*S. muehlenbergii*, S. *oligantha*, *S. pauciflora* var. *pauciflora*, *S. triglomerata*, *S. verticillata*]. Of these taxa, *S. triglomerata* is common, being found scattered throughout the state, while *S. verticillata* is fairly common in northeastern Illinois and in the sand areas in the Illinois River Valley. *Scleria muehlenbergii*, in contrast, is known from a few dozen collections in the wind-blown sand deposits of Cass, Kankakee, and Lee counties, while *S. oligantha* is known from a single poor quality collection from Hardin County. *Scleria pauciflora* is relatively rare in Illinois with a few specimens from wind-blown sand deposits in the northern part of Illinois and some from dry woodlands and prairies in the extreme southern part. It is difficult to separate the two varieties (var. *pauciflora* and var. *caroliniana*), as the major character difference is the abundance and length of the hairs on the leaf surfaces. This trait is somewhat variable in the Illinois specimens examined, but at the present time we have been unable to verify the existence of *S. pauciflora* var. *caroliniana* for Illinois.

Key Words: Cyperaceae, Illinois, nut rush, *Scleria*

INTRODUCTION

In 2004, while reviewing which Illinois plant species should be listed as threatened or endangered, the Endangered Species Protection Board found little information concerning the Illinois species of the genus *Scleria* (nut rush). Also, information about the distribution and habitat of the species was not very accurate, many herbarium specimens were incorrectly identified, and at that time, we could not verify the presence of one member of the genus that had been listed for the state. In addition, *Scleria* species are difficult to identify, while field identification of some taxa is tenuous at best.

Scleria is a genus of about 200 species widely distributed in tropical and warm-temperate regions of both hemispheres (Reznicek et al. 2002; Zhang et al. 2010). According to Kessler (1987), who synonymized some species accepted by Core (1936) and Fernald (1950), there were 14 species in North America. This treatment by Kessler (1987) was used as the basis for the "Flora of North America" by Reznicek et al. (2002). The 14 species listed are mostly restricted to the eastern half of the United States and adjacent Can-

ada with some of the species extending into the prairie and plains region, but not into, or west of the Rocky Mountain States. All 14 taxa are known from the southeastern United States.

Nut rush species are difficult to identify. First, being grass-like in general appearance, students, amateurs, and some professional taxonomists are immediately "turned-off." Also, the flowers are small and hard to dissect. *Scleria* and *Carex* are the only members of the Cyperaceae in our flora with unisexual flowers. These imperfect flowers occur in spikelets that consist of 3-10+ scales, the lower 2-4 scales being empty, the lower fertile scales being pistillate, the upper fertile scales staminate or sometimes empty. The individual unisexual flowers lack a perianth, the pistillate flower consisting of 1 (rarely 2) pistil(s) subtended by a scale, and the staminate flower consisting of 1-3 stamens borne in a scale.

In addition to the small and rarely seen flowers, an unusual structure of the achene provides an important taxonomic characteristic. The morphology of the achene, and the commonly associated hypogynium, are probably the most important diagnostic characteristics in species identification. The hypogynium, which is derived from receptacle tissue, is a hardened disc at the base of the achene (Tucker 1987). In some species the hypogynium forms a prominent collar, while in others it is an inconspicuous ridge around the point of achene attachment. Another unusual characteristic of the genus is a structure called the contra-ligule, which is a membranous flap on the rim of the leaf sheath on the opposite side from the blade.

METHODS

Specimens of *Scleria* were borrowed from most of the herbaria in Illinois, studied, and identified. These specimens were annotated and their distribution mapped. Also, some herbaria from surrounding states were examined for Illinois specimens. Most of the species were also observed and collected from the field. Attempts were made to relocate species that are rare, or had not recently been collected in the state, in connection with other floristic projects in which the authors and their colleagues were involved.

Listed below (alphabetically by acronym) are the locations and acronyms of the herbaria where specimens were examined: Chicago Botanic Garden, Glencoe, Illinois (CHIC); Northern Illinois University, DeKalb, Illinois (DEK); Eastern Illinois University, Charleston, Illinois (EIU); Field Museum of Natural History, Chicago, Illinois (F); USDA Forest Service, Harrisburg, Illinois (FS); University of Illinois, Urbana, Illinois (ILL); Illinois Natural History Survey, Champaign, Illinois (ILLS); Illinois State Museum, Springfield, Illinois (ISM); Illinois State University, Normal, Illinois (ISU); Missouri Botanical Garden, St. Louis, Missouri (MO); The Morton Arboretum, Lisle, Illinois (MOR); Western Illinois University, Macomb, Illinois (MWI); Purdue University Herbarium, West Lafayette, Indiana (PUL); and, Southern Illinois University, Carbondale, Illinois (SIU).

TAXONOMIC TREATMENT

As more botanical collecting occurred in Illinois the number of *Scleria* species known for the state increased. Mohlenbrock (2002) listed six taxa of *Scleria* for Illinois, five species, one with two varieties [*S. muehlenbergii, S. oligantha, S. pauciflora* (var. *pauciflora* and var. *caroliniana*), *S. triglomerata, S. verticillata*]. Earlier, Mohlenbrock (1986) listed the same taxa with one change, *S. muehlenbergii* was replaced by *S. reticularis,* while in 1975 Mohlenbrock listed 5 taxa, *S. oligantha* not being reported. Earlier, Jones (1971) listed only three species for Illinois (*S. pauciflora, S. triglomerata, S. verticillata*), while Jones and Fuller (1955) listed the same three taxa. The present treatment is based on Mohlenbrock (2002) which is consistent with the present treatment in the "Flora of North America" (Reznicek et al. 2002).

The sequence of species in our paper is alphabetical and not intended to convey phylogenetic relationships. However, the last species, *S. verticillata*, is quite different from the others in its spicate inflorescence and scented roots. This species, along with *S. hirtella* and a number of tropical species, has been placed in the segregate genus, *Hypoporum*.

Cyperaceae, Tribe Scleriae Nees

Scleria Bergius, Kongl. Vetensk. Akad. Handl. 26: 142, pl. 4, 5, 1765. -- Nut-rush.

Plants perennial or rarely annual herbs, rhizomes often present. S**tems** trigonous to triquetrous, glabrous, pubescent or scabridulous. **Leaves** basal and cauline, the lowest with much reduced blades, 3-ranked; sheath present, glabrous to pubescent; blades usually well developed, linear to filiform, midvein prominent; contra-ligule usually prolonged beyond top of sheath. **Inflorescence** terminal and usually axillary, paniculate to rarely spicate; bracts 1-3, leaf-like, reduced ascending or erect; peduncles present or not, trigonous, smooth or scabridulous on the angles. **Spikelets** with 3-10+ scales, the lower 2-4 scale empty, the lower fertile scale pistillate, the remaining fertile scales staminate or empty; floral scales ovate-deltoid to ovate-lanceolate. **Flowers** usually unisexual, the plants monoecious; perianth absent; staminate flowers with 1-3 stamens; filaments capillary; anthers narrowly linear, 2-4 mm long, apex usually mucronate or awned; pistillate flowers with one pistil; styles longer than stigmas; stigmas (2) 3, capillary. **Achenes** roundly trigonous to terete, globose or ellipsoid; surface smooth, tuberculate (warty), pitted, or lobed, rarely pubescent; **hypogynium** disk-like, lobed or entire, sometimes absent.

Key to the species of *Scleria* in Illinois

1. Inflorescence an erect, interrupted spike of several sessile glomerules; hypogynium, a short, cylindrical disk, or absent ..... 5. *S. verticillata*
1. Inflorescence of one or more terminal and lateral fascicles, paniculate; hypogynium well-developed.
   2. Achenes smooth and shining
      3. Hypogynium obscurely trigonous, with a whitish papillose crust, lacking tubercles ..... 4. *S. triglomerata*
      3. Hypogynium with 8-9 small, papillose tubercles ..... 2. *S. oligantha*
   2. Achenes tuberculate, or pitted, rarely also pubescent.

4. Achenes pitted, pubescent with tufts or lines of small hairs; hypogynium 3-lobed, the lobes oblong to lanceolate .....1. *S. muehlenbergii*
4. Achene tuberculate and papillate; glabrous; hypogynium with 6 globose tubercles in distinct pairs .....3. *S. pauciflora*

1. *Scleria muehlenbergii* Steudel, Nomencl. Bot. ed. 2, 2:543. 1841. -- Muhlenberg's nut-rush.

S. reticularis Michx. var. *pubescens* Britt.

Plants annual to short-lived perennial, loosely cespitose; rhizomes (in perennial plants) short, 1-2 mm thick; roots fibrous. **Stems** 20-90 (-125) cm tall, 1-3 mm wide, trigonous to subterete, often somewhat compressed, glabrous or lightly pubescent. **Leaves** with sheaths slightly winged, glabrous to pubescent; blades 10-30 cm long, 1-4 (-8) mm wide, linear, flat, glabrous; contra-ligules rotund-obtuse, 0.1-0.8 mm long, glabrous, with membranous margin. **Inflorescences** terminal and axillary, paniculate, 1.5-8 cm long; bracts 1-4 cm long, slender; peduncles (1.5-) 2-10 cm long, lowermost spreading or drooping. **Spikelets** bisexual or unisexual, 2-5 mm long, few-flowered; floral scales 3.0-4.5 mm long, 1.5-2.5 mm wide, ovate-lanceolate, keeled, green to stramineous to purplish, acuminate. **Achenes** (1.0-) 1.5-2.5 (-3.5) mm long, globose to ovoid, with obtuse, apiculate apex, conspicuously pitted, white or gray, with tufts or lines of minute, yellowish to purplish hairs; **hypogynium** distinctly 3-lobed, the lobes oblong to lanceolate, apex obtuse to subacute, appressed to achene base. **Flowering:** July, **Fruiting:** August. Damp sandy grasslands and in very shallow water; New York to Missouri south to Florida and Texas; Mexico; West Indies; northern South America.

Note: *Scleria muehlenbergii* is similar to *S. reticularis,* having a similar growth habit and morphological characteristics, and both have been reported for Illinois (Mohlenbrock 1986, 2002). We have not found *S. reticularis* in Illinois, but this species is known from Indiana and Wisconsin and could logically occur here. The two taxa are easily separated since the achenes of *S. muehlenbergii* have tufts or lines of very thin hairs that are commonly yellowish or purplish in color. These hairs are lacking on the achenes of *S. reticularis*. Mohlenbrock (2002) considered *S. muehlenbergii* very rare in Illinois, occurring only in a sand pond in Cass County; he also reported it from Lee Co. (Mohlenbrock 2001). However, we have located numerous other collections.

Specimens Examined: ILLINOIS: **Cass Co.:** moist peaty sand, E of Beardstown, 13 Aug 1957, *R.T.Rexroat 4158* (ILLS); edge of peaty swamp, E of Beardstown, 20 Aug 1957, *R.T.Rexroat 4232* (ISM), *4233* (ISM), *4234* (ISM), *4235* (F, ISM), *4236* (ILLS) *4237* (ISM), *4239* (ISM); moist peaty sand W of Virginia, 1 Oct 1958, *R.T.Rexroat 5520* (ISM), *5521* (ILLS); natural sand pond W of Virginia, 5 Sep 1958, *R.T.Rexroat 5351* (ISM), *5352* (ISM), *5353* (ISM); sand pond SE of Beardstown, 19 Aug 1960, *R.T.Rexroat 7074* (ISM), *7075* (ILLS), *7076* (ISM), *7077* (ISM); pond SE of Beardstown, 12 Sep 1960, *R.T.Rexroat 7173* (ISM, SIU), *7174* (ISM); sand pond, SE of Beardstown, 7 Sep 1969, *R.T.Rexroat 17163* (MWI), *17164* (MWI), *17165* (MWI), *17166* (MWI). **Kankakee Co.:** low area along ditch, Sweet Fern Sand Savanna, 9 Aug 2002, *P.B.Marcum 1514* (ILLS). **Lee Co.:** interdunal pond near Amboy, 15 July 1959, *J.B.Long 977* (ILL); interdunal pond near Amboy, 28 July 1959, *J.B.Long 988* (ILL);

sphagnum covered depression near Amboy, 3 Aug 1959, *J.B.Long 991* (ILL); interdunal pond near Amboy, 11 Sep 1959, *J.B.Long 1012* (ILL); Amboy Township, Sec. 33, found in three locations on my farm, 27 Sep 1969, *J.B.Long s.n.* (ISM); low sandy swale, Amboy Township, Sec. 33, 16 Aug 1969, *J.B Long s.n.* (ISM); Amboy Township, Sec. 33, this plant varies from none yearly back to abundant, 27 Jul 1991, *J.B.Long 1248* (ISM), *1249* (ISM); border of sandhill hollow, "Old Farm," 14 Aug 1990, *J.Long 1196* (ILL); moist sand barren, "The Old Farm," 22 Aug 1990, *J.Long 1201* (ILL); sandy barren shore of pond, Rocky Ford, 1 Oct 1990, *J.Long 1213* (ILL).

2. Scleria oligantha Michaux, Fl. Bor.-Amer. 2:167. – nut-rush.

Plants perennial, with loosely clustered stems; rhizomes 1-8 cm long, 3-5 mm thick, hard, stout, nodulose; roots fibrous. **Stems** 30-60(-75) cm tall, 1-2.5 mm wide, trigonous, glabrous to pubescent. **Leaves** with sheaths usually narrowly winged, glabrous to pubescent; blades 15-30 cm long, 2-6 mm wide, linear, flat, glabrous; contra-ligules ovate, 1.3-3 mm long, scabridulous, with conspicuous hyaline border. **Inflorescence** terminal and sometimes axillary, paniculate, 0.5-2.5 cm long**;** bracts 2-11 cm long, relatively slender; peduncles 1-2 cm long, erect. S**pikelets** bisexual to staminate, 3-8 mm long, few-flowered; floral scales 3-6 mm long, 1.5-3 mm wide, ovate-lanceolate, slightly keeled, green to purplish brown, apex acuminate. **Achenes** 3-4 mm long, ovoid to subglobose, with obtuse, usually apiculate apex, smooth, glossy, white; **hypogynium** base obtuse trigonous, with 8-9 small, rounded or elongated , granular tubercles. **Flowering:** June-July, **Fruiting:** July-August. Mesic to xeric woods, glades, and wet meadows; New Jersey, Ohio, Missouri south to Texas, and Florida; Mexico; Central America.

Note: Though reported as "scattered in moist woods" in Illinois by Mohlenbrock (2002), and listed for Illinois by Reznicek et al. (2002), we have found only one specimen (see below) that we have tentatively identified as *S. oligantha*. This specimen is immature and lacks a root system. On this specimen, we found one achene that was nearly mature. The surface of the achene was smooth and the hypogynium consisted of eight granular tubercles.

Specimen Examined: Illinois: Hardin Co.: locally common at edge of limestone glade opening now grown closed by red cedar at Barker Bluff Natural Area, center Sec. 7 T12S R10E, growing with *Ratibida pinnata, Manfreda virginica, Quercus muehlenbergii, Juniperus virginiana,* and *Verbesina virginica,* 8 Jul 1998, *M.A.Basinger & J.P.Shimp 11369* (FS).

3. *Scleria pauciflora* Muhlenberg ex Willdenow, Sp. Pl. 4: 318, 1805. -- papillose nut-rush, few-flowered whip-grass.

Scleria pauciflora var. *effusa* C.B. Clarke; *Scleria ciliata* Michx. var. *pauciflora* (Muhl. ex Willd.) Kükenthal

Plants perennial, with loosely clustered stems; rhizomes 1-10 cm long, 3-5 mm thick, hard, stout, nodulose; roots fibrous. **Stems** 20-50(-70) cm tall, 0.6-1.5 mm wide, trigonous, glabrous or sparsely to densely pubescent. **Leaves** with sheaths not winged, glabrous to densely short-pubescent; blades 10-35 cm long, 0.6-2 (-2.5) mm wide, linear, flat

to commonly plicate, glabrous or pubescent; contra-ligules obtuse to triangular, 0.2-0.7 mm long, scabridulous, with narrow hyaline border. **Inflorescences** terminal and sometimes axillary, paniculate, 0.4-2.0 cm long; bracts 1-10 cm long, very slender; peduncles 1-5 cm long, erect. **Spikelets** bisexual or staminate, 3-6 mm long, 3-6 flowered; floral scales 2-5 mm long, 2-3.3 mm wide, ovate-lanceolate, slightly keeled, green to purplish tinged, apex acuminate. **Achenes** 1.3-2.5 mm long, ovoid to globose, with obtuse, apiculate apex, irregularly transversely tuberculate and papillate, sometimes the papillae near the base elongate and spinulose; **hypogynium** narrow, somewhat trigonous, with 6 finely puberulent globose tubercles in distinct pairs. **Flowering:** July-August, **Fruiting:** August-September. Moist sandy soil of grasslands and open woods; New Hampshire to Kansas, south to Texas and Florida; West Indies (Cuba).

Note: Mohlenbrock and Ladd (1978) recorded this species from Henry and Union counties, but we could not confirm these distribution records.

Scleria pauciflora Muhl. ex Willd var. *caroliniana* A. Wood has been reported for Illinois (Mohlenbrock 1976, 2002; Reznicek et al. 2002). The two varieties have nearly identical geographic ranges but we have not been able to verify the existence of var. *caroliniana* for Illinois; no specimens of this variety have been found during our study. The two varieties differ only in the type and extent of pubescence, var. *parviflora* being glabrous to densely hairy, the hairs less than 0.4 mm long, var. *caroliniana*, in contrast, is villous-ciliate with spreading hairs 0.5-1 mm long on the stems, leaves, and bracts (Fairey 1967, 1969, Reznicek et al. 2002). Many specimens of *S. pauciflora* var. *pauciflora* that we have examined have dense pubescence, particularly on the lower leaf sheaths (some of these had been misidentified as var. *caroliniana*). The hairs of these specimens are short, mostly less than 0.3 mm long, not at all like the villous-ciliate hairs of var. *caroliniana* that exceed 0.5 mm in length. The specimen cited by Mohlenbrock (1976) from Lee Co. (*Long 792*, ILLS) has short hairs and we consider it var. *pauciflora*.

Specimens Examined: ILLINOIS: **Hardin Co.:** woodland, 2.5 miles west of Elizabethtown, 5 Jun 1952, *H.E.Ahles 6206* (EIU, ILL, ISM); dry woodland in compartment 53, NEQ Sec 11 T12S R8E, 15 Jun 1991, *L.R.Stritch, E.L.Shimp & J.P.Shimp 2606* (FS). **Iroquois Co.:** sand savanna, Iroquois County State Conservation Area, 25 Jul 2001, *L.R.Phillippe 33403* (EIU, ILLS). **Johnson Co.:** no date, *F.Brendel s.n.* (ILL); dry/dry-mesic upland oak-hickory forest in compartment 34, SEQ Sec 36 T11S R4E, 7 Aug 1992, *J.P.Shimp & L.R.Stritch 2959* (FS). **Kankakee Co.:** sandy roadside, Liebert Natural Area, 26 Jul 2002, *D.T.Busemeyer & L.R.Phillippe 1018* (ILLS); edge of black oak sand savanna, Sweetfern Natural Area, 9 Aug 2002, *P.B.Marcum 1524* (ILLS). **Lee Co.:** Amboy Township, Sec. 7, 27 Aug 1969, *J.B.Long s.n.* (ISM); sand barren, Sec 12 T19N R10E, 17 Jul 1958, *J.B.Long 786* (ISM); sand barren, 17 Jul 1958, *J.B.Long 792* (ILLS). **Massac Co.:** common in fields, NEQ of SWQ Sec 27 T14S R5E, 30 Jun 2004, *J.Schwegman s.n.* (ILLS). **Pope Co.:** prairie, Dean Cemetery Prairie, 7 Jul 1992, *M.A.Basinger 4565* (ILLS); drainage area in dry prairie, Dean Cemetery Prairie, Sec 23 T15S R6E, 19 Jul 1991, *C.Giedeman s.n.* (SIU); dry prairie, Dean Cemetery Prairie, 19 Jul 1991, *F.Latortue s.n.* (SIU); dry restored tall grass prairie, Dean Cemetery Prairie, NEQ Sec 23 T15S R6E, 11 July 1991, *B.Middleton s.n.* (SIU); small barren remnant, Azots Field, 16 Jun 2004, *J.Schwegman s.n.* (ILLS); on Stinson Trail, barren remnant, near Azots, 9 Jul 1978, *J.Schwegman 2937* (ISM); dry juniper-oak savanna in compart-

ment 29, NEQ of SEQ Sec 10 T12S R5E, Hayes Creek Canyon Watershed, 26 Jul 1981, *L.R.Stritch 1760* (FS); dry-mesic barrens, Dean Cemetery East Biological Area, NEQ of NWQ Sec 23, T12S R6E, 1 Aug 1994, *E.F.Ulaszek 2418* (FS). **Randolph Co.:** dry woodland above N-side of Rockcastle Creek Canyon, 2 miles S of Steeleville, 13 Jul 2010, *R.W.Nyboer s.n.* (EIU). **Will Co.:** Braidwood Dunes and Savanna Nature Preserve, dry-mesic sand prairie, 16 June 2005, *L.R. Phillippe 37642* (ILLS) and 2 Sep 2006, *L.R. Phillippe 38029* (ILLS). **Williamson Co.:** sandstone glade, Crab Orchard National Wildlife Refuge, SWQ of SWQ Sec 34 T10S R1E, 4 Jul 1983, *E.F.Ulaszek 387* (ILLS).

4. ***Scleria triglomerata*** Michaux, Fl. Bor.-Amer. 2: 168. 1803. -- tall nut-rush, whip-grass.

S. nitida Muhl. ex Willd.; *Scleria minor* (Britt.) Stone; *Trachylomia triglomerata* (Michx.) Nees; *Scleria triglomerata* var. *gracilis* Britt.; *Scleria flaccida* Steud.

Plants perennial, with loosely clustered stems; rhizomes 1-3 cm long, 3-5 mm thick, hard, stout, nodulose; roots fibrous. **Stems** 40-100 cm tall, 1-4 mm wide, trigonous, glabrous to ciliate on the ridges. **Leaves** with sheaths not winged, glabrous to pubescent; blades 15-30 cm long, 3-9 mm wide, linear, flat, glabrous to slightly pubescent; contra-ligules ovate-deltate, 1.3-4 mm long, scabridulous, with conspicuous hyaline border. **Inflorescence** terminal and axillary, paniculate, 1.5-4.5 cm long**;** bracts 2-11 cm long, relatively slender; peduncles 1-2 cm long, erect. S**pikelets** bisexual to staminate, 3-9 mm long, many-flowered; floral scales 2-5 mm long, 2.1-3.2 mm wide, ovate-lanceolate, slightly keeled, green to purplish brown, apex cuspidate, 1-6 mm long. **Achenes** (1.5-) 2-3 (-3.5) mm long, ovoid to subglobose, with obtuse, usually apiculate apex, smooth, glossy, white; **hypogynium** narrow, obscurely trigonous with a whitish papillose crust. **Flowering:** June-July, **Fruiting:** July-August. Damp fields, or in dry soil, prairies, savannas, and mesic sand prairies; Massachusetts, southern Ontario, and Iowa south to Florida and Texas; Puerto Rico; Mexico.

Note: Mohlenbrock and Ladd (1978) recorded this species from Cass and Jo Daviess counties, but we could not confirm this.

A segregate, with hairy sheaths and larger achenes, *S. minor* was accepted by Fernald (1950) and Fairey (1967) but synonymized by Core (1936) and Kessler (1987) with slight discussion. It occurs in the eastern United States from New York south to Texas and Florida (Fernald 1950, Reznicek et al. 2002), and is entirely within the range of *S. triglomerata*. *Scleria minor* has not been reported for Illinois, and we have found no Illinois collections fitting this taxon.

Specimens Examined: ILLINOIS: **Adams Co.:** railroad prairie E of Fowler, 10 Jun 1965, *R.A.Evers 83699* (ILLS); E part of county, high limestone bluff, 30 Sep 1963, *R.T.Rexroat 9179* (ISM); SE part of county, high dry hill over limestone, 4 Oct 1963, *R.T.Rexroat 9206* (ISM); dry red clay hill, 13 Jul 1964, *R.T.Rexroat 9390* (ISM), *9391* (ISM), *9392* (ISM). **Carroll Co.:** mesic sand prairie, Mississippi Palisades State Park, 29 Aug 1992, *W.C.Handel 617* (ILLS). **Cass Co.:** E of Beardstown, 13 Aug 1957, *R.T.Rexroat 4159* (ISM), *4160* (ISM); E of Beardstown, 10 Sep 1957, *R.T.Rexroat 4316* (ISM); near Virginia, 13 Jul 1964, *R.T.Rexroat 9390* (SIU). **Cook Co.:** wet meadow,

Washington Heights, 22 Aug 1902, *R.Bebb 1062* (F, MO); N Silva Bud, Chicago, 16 Aug 1904, *F.C.Gates 289* (F); along railroad, N of Jefferson Park, Chicago, 12 Jul 1893, *W.S.Moffatt s.n.* (ILL); sandy prairie E of Thornton, 27 Jul 1986, *F.Swink, Johnson & Sullivan 6826* (MOR). **Effingham Co.:** railroad, ½ mile SW of Mason on Rt. 37, 10 Aug 1980, *P.Shildneck 11464* (ISM); railroad prairie ½ miles SW of Mason, 10 Aug 1980, *P.Shildneck 12325* (ILL); Rt. 37 between Mason and Edgewood, 6 Aug 1983, *P.Shildneck 12675* (ISM); Rt. 37 between Mason and Edgewood, 25 Jul 1990, *P.Shildneck 15466* (ISM). **Fulton Co.:** N of Anderson Lake, 16 Jul 1958, *R.T.Rexroat 5211* (ISM, SIU); N of Anderson Lake, 14 Aug 1961, *R.T.Rexroat 7858* (ISM); S of Astoria, 20 Jun 1958, *R.T.Rexroat 4920* (ISM); gravelly clay, sterile moss covered hillside, 16 Jul 1958, *R.T.Rexroat 5212* (ISM, MWI). **Grundy Co.:** wet prairie, Goose Lake, SE of Morris, 1 Jul 1970, *R.A.Evers 102844* (ILLS); railroad right-of-way, in Braceville, 5 Jul 1975, *R.Schulenberg & A.Kropp 75-770* (MOR). **Henderson Co.:** prairie near Oquawka, 18 Jul 1972, *H.N.Patterson s.n.* (F); Oquawka, no date, *H.N.Patterson s.n.* (F, MO). **Henry Co.:** Munson Cemetery, 24 Jun 1982, *R.R.Clinebell 145* (MO). **Iroquois Co.:** E of Watseka, 14 Jun 1962, *R.A.Evers 74030* (ILLS, ISM); sand prairie, Iroquois County Conservation Area, 1 Jul 1970, *R.A.Evers 102869* (ILLS); near Beaverville, 18 Jul 1948, *G.N.Jones 18818* (ILL); dry-mesic savanna, Iroquois County State Conservation Area, 25 Jul 2001, *L.R.Phillippe 33401* (EIU, ILLS); dry-mesic savanna, Hooper Branch Savanna Nature Preserve, 9 Aug. 2001, *L.R.Phillippe 33492* (ILLS); sand, SEQ of SEQ Sec 24 T27N R12W, 14 Aug 1977, *R.Schulenberg & E.Hedborn 508* (MOR). **Jasper Co.:** mesic prairie, Prairie Ridge State Natural Area, 4 Jul 1996, *B.Edgin 438* (EIU). **Kankakee Co.:** sandy area, Liebert Natural Area, 26 Jul 2002, *D.T.Busemeyer & L.R.Phillippe 1019* (ILLS); sandy swamp, SE of St. Anne, 29 Jun 1944, *G.D.Fuller 8930* (ILL); E of St. Anne, 1 Jul 1944, *V.O.Graham 8930* (ISM); E of St. Anne, 1 Jul 1944, *V.O.Graham 9337* (ISM); sand prairie, Kankakee, 10 Jun 1871, *E.J.Hill s.n.* (ILL); near St. Anne, 16 Jun 1940, *G.N.Jones 11504* (ILL); sand prairie, Sweetfern Sand Savanna, 9 Aug 2002, *P.B.Marcum 1518* (ILLS); wet-mesic prairie, 9.4 miles NE of St. Anne, *L.R.Phillippe & M.A.Feist 34725* (EIU, ILLS); natural prairie, 3 miles SE of Custer Park, 24 Aug 1947, *J.A.Steyermark 64886* (F, ILL); old crescent dune area, 2 miles S of Leesville, 26 Jun 1992, *G.Wilhelm & A.Reznicek 20569* (MOR); Sweetfern Sand Savanna Land and Water Reserve, old field, 9 Aug 2002, *P.B. Marcum et al. 1518* (ILLS); IDNR property (Leesville East), about 11 miles E of St. Anne, shallow ponded area with Quercus palustris, 3 Jul 2002, *M.A. Feist & G. Spyreas 1712* (ILLS). **Lake Co.:** wet meadow, Camp Logan, 29 Jun 1906, *F.C.Gates 2772* (F, ILL); sedge meadow, State Beach Park, 10 Aug 1985, *U.Rowlett 1728* (F); **Lee Co.:** Bartell's Prairie, Winddrift Sanctuary 3 miles NW of West Brooklyn on Shaw Road, 16 May 1986, *P.K.Armstrong 121* (MOR); original prairie near Amboy, 4 Aug 1932, *V.H.Chase 4702* (ILL); sandhills, May Tp., 21 Jun 1951, *V.H.Chase 11997* (ILL); dry-mesic sand prairie, Foley Sand Prairie Nature Preserve, 11 Aug 2002, *J.E.Ebinger 31039* (EIU); along railroad, 8 Aug 1956, *J.B.Long 184* (ILL); moist sand prairie, 22 Jun 1958, *J.B.Long 753* (ILL); S of Amboy, 15 Jun 1988, *J.B.Long 1079* (ISM); Nichols Prairie, 18 Jun 1990, *J.B.Long 1164* (ILL); native wet prairie, Richardson Wildlife Foundation, 10 Jul 1997, *L.R.Phillippe & W.C.Handel 29017* (ILLS). **Mason Co.:** sandy soil, Sand Prairie-Scrub Oak Nature Preserve, 14 Jul 1977, *A.G.Jones 4012* (ILL); mesic sand prairie, Matanzas Prairie Nature Preserve, 14 May 1990, *M.Morris & L.R.Phillippe 357* (EIU, ILLS); ephemeral sand pond, Sand Prairie-Scrub Oak Nature Preserve, 21 Aug 2003, *L.R.Phillippe 36097* (EIU, ILLS); NEQ Sec 4 T20N R9W, 30 Aug 1982, *S.Tyson 1174*

(ISM). **McDonough Co.:** dry bluff top, Argyle Lake State Park, 6 Aug 1984, *R.D.Henry & A.R.Scott 4311* (MWI), *4312* (MWI), *4313* (MWI). **McHenry Co.:** Ringwood, *G.Vasey s.n.* (ILL). **McLean Co.:** 1 Jul 1858, F.Brendel Herbarium (ILL). **Ogle Co.:** Pine Rock Natural Area, 4 miles E of Oregon, 22 Aug 1969, *D.R.Wade & D.E.Wade C-2156* (ISM). **Peoria Co.:** dry wooded hillside near Princeville, 29 Aug 1906, *V.H.Chase 1252* (ILLS); hilltop prairie, Limestone Twp., 16 Jul 1960, *V.H.Chase 16126* (ILL, ISM, MOR); sandy banks above Rocky Glen near Peoria, Jul 1891, *F.E.McDonald s.n.* (ILL). **Pope Co.:** prairie, 5 miles S of Bay City, 12 Jun 1968, *R.A.Evers 95172* (ILLS); old field SW of Bay City, 23 Jul 1970, *R.A.Evers 103102* (ILLS); tall grass prairie, Dean Cemetery Prairie, 11 Jul 1991, *B.Middleton s.n.* (SIU); dry field, ½ miles WSW of Azotus Church, 6 Jul 1967, *J.Schwegman 1222* (SIU); dry-mesic barrens, Dean Cemetery East Ecological Area, 23 Jun 1994, *E.F.Ulaszek 2091* (FS). **Warren Co.:** mesic prairie, 3.5 miles E of Berwick, 10 Jul 1973, *R.A.Evers 110724* (ILLS). **Will Co.:** dry-mesic sand prairie, Braidwood Dunes and Savanna Nature Preserve, 16 Jun 2005, *L.R.Phillippe 37644* (EIU, ILLS) and *37645* (ILLS); wet meadows E of Braidwood, 16 Jul 1935, *R.A.Schneider 9715* (ILLS); wet sand prairie near Braidwood, 16 Jun 1973, *R.Schulenberg, M.Madeny & G.Dewey s.n.* (MOR); disturbed dry-mesic sand prairie, 13 Aug 2007, *L.R. Phillippe & P.B. Marcum 40037* (ILLS); mesic prairie, Wilmington Shrub Prairie Nature Preserve, 3 miles E of Braidwood, 28 Jun 2007, *L.R. Phillippe 39812* (ILLS). **Winnebago Co.:** Fountaindale, 1868, *M.S.Bebb s.n.* (F); bog, Beloit, 1 Aug 1947, *E.W.Fell & G.B.Fell 47-148* (ISM, MWI); bog, Beloit, 8 Aug 1947, *E.W.Fell & G.B.Fell 47-171* (ISM).

5. ***Scleria verticillata*** Muhlenberg ex Willdenow, Sp. Pl. 4: 317. 1805. -- low nut-rush, whorled nut grass.

Hypoporum verticillatum (Willd.) Nees

Plants annual, loosely tufted; rhizomes none; roots fibrous, with citrus-like scent when fresh. **Stems** 10-60 cm tall, 0.3-0.8 mm wide, trigonous, glabrous. **Leaves** with sheaths pilose; blades 5-30 cm long, 0.5-1.5 mm wide, filiform, flat, glabrous; contra-ligules scarcely prolonged, 0.1-0.3 mm long, with few stiff straight hairs to 0.3 mm long. **Inflorescences** of 2-8 erect to oblique sessile glomerules, well spaced on a rachis 4-15 cm long; bracts 3-8 mm long, slender; peduncles absent or nearly so. **Spikelets** bisexual, 2-3 (-4) mm long, few-flowered; floral scales 2-4.5 mm long, 0.7-1.5 mm wide, oblong-lanceolate, keeled, reddish-brown, acuminate, with bristle-like tip. **Achenes** 1-1.5 mm long, broadly ovoid to subglobose, with obtuse, usually apiculate apex, irregularly reticulate or tuberculate (reticulations transverse), white; **hypogynium** a small brownish ridge at the base of the achene, or absent. **Flowering:** July, **Fruiting:** August. Damp grasslands, marl flats, interdunal swales, fens; Connecticut, New York, extreme southern Ontario, Michigan, and Minnesota, south to Florida and Texas; Mexico; West Indies.

Note: This species resembles the pantropic *S. hirtella* Sw., a perennial with pilose floral scales.

Specimens Examined: ILLINOIS: **Cook Co.:** springy and marshy ground, SE of Elgin City limits, 2 Sep 1919, *H.C.Benke 3674* (F); marl flats, fen immediately S of Bluff City Cemetery, 5 Oct 1983, *E.Evert 6425a* (MOR); sandbar along creek in fen, 1 Aug 1984,

N.Stoynoff 545 (MOR); marly fen, SE edge of Elgin, S of Bluff City Cemetery, 3 Oct 1977, *G.Wilhelm, W.Hess & M.Grintz 4162* (MOR); edge of tufa flat, SE edge of Elgin, S of Bluff City Cemetery, NEQ of NEQ of NWQ Sec 30 T41N R9E, 25 Aug 1977, *G. Wilhelm, D. Young, R.Moran & M.Madany 4045* (MOR); **Kane Co.:** Nelson Lake, 16 Sep 1984, *D.Young s.n.* (MOR). **Lake Co.:** sand swale, Illinois Beach Nature Preserve, 2 Sep 1988, *M.Bowles 842* (MOR); marshland, 2.5 miles S of Wauconda, 21 Sep 1961, *R.A.Evers 71702* (ILLS); beach, *Liatris spicata* prairie, 24 Aug 1909, *F.C.Gates 3210* (F); Illinois Beach State Park, 27 Aug 1983, *U.Rowlett 1365* (F); alkaline marshy ground. 6 miles N of Barrington, W of Tower Lake and N of Kelsey Road, property of Dr. Wm. Holmes, 15 Sep 1956, *J.A.Steyermark 82628* (ILL); near Dead River, Illinois Beach State Park north of Waukegan, 15 Aug 1953, *F.A.Swink 2551* (F). **Mason Co.:** moist peaty sand, SE of Havana, 18 Aug 1957, *R.T.Rexroat 4216* (ISM), *4217* (ISM), *4218* (EIU), 4219 (ILLS), *4220* (ISM), *4221* (ISM). **McHenry Co.:** Spring Hill Farm, SWQ of NWQ Sec 21 T44N R8E, 16 Aug 1976, *R.C.Moran s.n.* (MOR). **Peoria Co.:** Peoria, no date, *F.E.McDonald s.n.* (ILL). **Will Co.:** wet peaty soil on boggy hillside, Troy, 15 Sep 1911, *E.J.Hill 30.1911* (ILL). **Woodford Co.:** cold bogs in Illinois River bottom one mile beyond upper ferry, Aug 1887, *F.E.McDonald s.n.* (ILL); Sep 1887, *F.E.McDonald s.n.* (ILL).

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Major Damages in Northern Illinois from a Record-Setting Rainstorm in 2010

Stanley A. Changnon
Changnon Climatologist
Mahomet, IL 61853
Telephone 217/586-5691
Chief Emeritus Illinois State Water Survey

ABSTRACT

A record-setting July rainstorm fell in 24 hours in northern Illinois. Amounts exceeded 10 inches in northwest Illinois (rural) and northeastern Illinois (urban). Many rain amounts that fell in 3-, 6-, and 24-hour periods exceeded totals expected to occur only once in 100 years. Regional rivers quickly reached levels 3 to 10 feet above flood stages. Regional flooding affected 30,000 homes in the Chicago area, damaged crops and dairy farming, and damaged railroads and halted movement of trucks and trains in both areas. Property damages totaled $184 million, much higher than the state's average flood loss of $79 million. FEMA ultimately awarded $320 million in aid, the largest amount ever awarded Illinois for any past storm disasters. The July storm losses and costs totaled $620 million.

INTRODUCTION

Heavy rains fell in northern Illinois on July 23-24, 2010, creating severe flooding in many locales and major damages. The total rain was above 10 inches in extreme northwestern Illinois (Jo Daviess and Stephenson Counties) and in northeastern Illinois (Cook County), as shown in Figure 1. Rainfall exceeded 4 inches across northern Illinois from Carroll County eastward to Du Page and Cook Counties. Most locales received the heavy rainfall in 24 hours or less, and some places had amounts expected to occur only once in a 100-year period.

Most of the rain fell from the afternoon of July 23 until noon on July 24. The total storm rainfall pattern (fig. 1) shows two small areas where amounts exceeded 10 inches. These both occurred in 24 hours or less and the 100-year value for 24 hours is 8 inches (Huff and Angel, 1989), revealing the record-setting level of these amounts.

The heavy rains were the result of strong frontal activity. Northern Illinois, southern Wisconsin, and eastern Iowa were in and near frontal zones from midnight on July 22 until late on July 24. The resulting atmospheric instability created many storms and several mesoscale storm complexes across the 3-state area. A sizable convective system moved from Iowa into northern Illinois and southern Wisconsin producing rains exceeding 2 inches (fig. 1).

Rains began in northwestern Illinois early on July 23 and ended in the afternoon of the 23rd. Then, storms began again late on the 23rd and lasted until the morning of the 24th. In northeastern Illinois rains began on the afternoon of July 23 and ended by mid-day on July 24, largely a result of a strong south-moving cold front that pushed to the south, leaving stable atmospheric conditions in the Illinois storm areas.

The paper illustrates the rainfall patterns for various periods of time ranging from when the heaviest rainfall fell in 3 hours up to the storm totals. An evaluation of the rain amounts in a historic-statistical context is presented, followed by descriptions of the physical and economic impacts the heavy rains caused.

RAINFALL

The storm rainfall pattern across northern Illinois and parts of Iowa and Wisconsin is presented in figure 1. This shows two major heavy rain areas: one in northeastern Illinois, and one in northwestern Illinois. Rainfall exceeded 12 inches in an area west of Freeport, and an area of more than 10 inches fell in Chicago. The July 2010 storm's rain totals in Chicago and Rockford both rated as the third highest 24-hour amounts since records began in 1890.

Rainfall exceeding 10 inches fell over much of a 3-county area in northwestern Illinois, and a small area in Jo Daviess and Carroll Counties had more than 12 inches. The heaviest rain fell from midnight on July 22 until noon on July 23. This storm period produced amounts from 2 inches up to 6 inches in northwestern Illinois. A secondary heavy rain period began late in the evening on July 23 and continued until 7 AM on July 24. This second storm system produced 1 to 4 inches of rain in northwestern Illinois and also eastward across northern Illinois. Rain at Rockford in the first period was 5.1 inches and then 3.2 inches in the second rain period. The heavy rains also extended into extreme southern Wisconsin and eastern Iowa (fig. 1).

At most locations in Cook County the rainstorm began at 10 PM on July 23 and ended by 10 AM on July 24. Most of the rainfall fell in 14- or 15-hour periods. The heaviest rain fell along a narrow west-east path (fig. 1) with less than 6 inches in northern Cook county and less than 4 inches in the southern end of Cook County. As shown in figure 1, amounts in the suburbs west of Chicago ranged from 4 to 6 inches. The small area of heavy rain likely resulted from local n urban effects on the atmosphere that enhanced the rainfall.

Figure 2 shows the heaviest 3-, 6-, and 12-hour rainfalls in Cook County. The data are from a dense network of 25 recording raingages in Cook County, and these data allowed a detailed time and space analysis of the heaviest rains in that area. All had their highest amounts in the center of Chicago. The heaviest rainfall at most raingages occurred in a 3-hour period. For example, gage 10, which had a storm total of 10.1 inches, had a peak of 4.6 inches in three hours, from 11 PM to 2 AM. This rates as a once in 100-year amount for 3 hours (Huff and Angel, 1989). A secondary peak at gages 8, 9, and 10 was 2.8 inches from 4 to 6 AM.

The storm totals in northwestern Illinois, where 8 inches or more fell in 24 hours, represented values expected at least once in 100 years. The areas of 10 to 12 inches were exceptionally high, setting local records and well beyond the 100-year frequency.

The frequencies of the heaviest rain amounts in 3-, 6- and 12-hour periods in Cook County (fig. 2) reveal that all rainfall in central Chicago had 100-year frequencies at all three durations, with lesser frequencies to the north and south. Amounts at gages 1 and 2 (north) and gages 24 and 25 (south) were only once in 2-year events.

IMPACTS

The major physical impact of the rainstorm was flooding of several streams and rivers in northern Illinois and areas alongside these rivers. The Illinois River reached well above flood stage by 8 to11 feet all the way from Morris to Hardin where it joins the Mississippi. The Mississippi River became 2 to5 feet above flood stage from Keokuk south to Cairo, Illinois. Localized rivers that flooded include the Rock River, which crested at 12.4 feet (2.4 feet above flood stage). Tributaries of the Rock also flooded including the Kishawaukee (crested 4 feet above flood stage), and Pecatonica (peaked 3 feet above flood stage). The Plum and Apple Rivers, which flow directly into the Mississippi, were also much above flood stage. In the Chicago area, flooding occurred along the north branch of the Chicago River, the Des Plaines River, Du Page River, and Fox River.

Damaging impacts occurred in four sectors. This included property losses, transportation damages, agricultural losses, and reduced retail sales.

Property losses occurred to homes, businesses, and vehicles in Chicago. Several suburbs southwest and west of the city had extreme flooding in over 30,000 homes. This included parts of Joliet, Orland Park, Romeoville, Hillside, Riverside, Cicero, Westchester, and Lemont (Chicago Tribune, August 4). Insured property losses totaled $105 million. The insurance industry defines losses greater than $25 million as a catastrophe; hence, the damages on July 23-24 were a catastrophe, creating major costs for several insurance firms. Property losses in the northeast area occurred along the four Chicago area rivers listed above. River flooding plus slow drainage in Chicago brought excessive house and building flooding, and the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) faced this major flooding with sewage stained waters and could not store it in its new tunnel and reservoir system. They estimated that 60 billion gallons of water had fallen over the city (Chicago Tribune, July 26). The MWRDGC chose to release 6.5 billion gallons of polluted flood waters into Lake Michigan to reduce the urban flooding, and the releases were through the Wilmette Channel and Chicago River Locks (Chicago Tribune, August 26) These polluted waters also led to beach closures for many days. Cicero sued the city over its flood losses, claiming the MWRDGC had failed to store and remove flood waters when needed (Chicago Tribune, August 4).

Property losses in northwestern Illinois occurred at farms and at communities along the Plum and Rock Rivers. Over 1,000 homes in this area were flooded (MRCC, July 20).

Surface transportation was damaged in both heavy rain areas. In Chicago and its suburbs more than 100 viaducts were flooded along with many roads and several highways,

collectively halting traffic for 2 to 3 days (Chicago Tribune, July 26). Several Metra commuter trains had to cancelled on routes in the southwest and west of Chicago (Chicago Tribune, August 4). Hundreds of vehicles were flooded and badly damaged. Flooding in northwestern Illinois caused many state highways and rural roads to be overcome with water and most were closed for 2 to 3 days (MWRC, July 20). A highway bridge was washed out at Elizabeth (FarmWeek, August 2010).

Railroads in the northwest area suffered serious damages (Railroads Illustrated, October). In the northwest area the Canadian National mainline experienced a 200-foot long landside that covered the tracks, and this line also had two track washouts. These damages stopped all trains for three days. A rush of flood waters on the Plum River washed out a railroad line and rail yards at Savanna (fig. 1), and many rail cars were knocked off the tracks. These fast waters also eroded a bridge support on Route 84 in Savannah, leading to a physical separation of the community. The flooding closed the mainline of the BNSF for two days halting 27 trains. The flooding also had detrimental effects on Amtrak passenger trains in the Chicago metropolitan area.. Twelve trains scheduled to depart Chicago on July 24 were canceled, greatly altering passenger movements and creating a major loss of business. Thirty-two passenger trains heading into Chicago were delayed several hours. Many freight trains in northern Illinois carrying perishable foods to Chicago were halted by flooded right-of-ways. These train delays led to the loss of many perishable foods, creating sizable costly losses.

Agricultural losses resulted from the heavy rains and subsequent flooding in northwestern Illinois. Several dairy farms were closed for 4 to 5 days with no milk produced, and cows at two farms had to be moved to farms with high grounds to escape the deep waters in the fields and barns (FarmWeek, August). Many areas of farm land were flooded, damaging the corn and soybean crops in some areas and totally ruining the crops in 12 square miles (FarmWeek, September).

Flooded streets, highways, and viaducts in northeastern Illinois reduced efforts to shop. Hence, retail sales were reported down 45 percent for 3 days (Chicago Tribune, September 2).

Responses to the flood damages began when Illinois Governor Quinn declared 12 counties as disaster areas. Ten were in northwestern Illinois and two in the Northeast (Cook and DuPage). The Federal Emergency Management Agency (FEMA) assessed damages throughout the region. On August 19 President Obama declared seven counties to be disaster areas, making them eligible for funds to repair homes and businesses (Chicago Tribune, September 2). Persons with damages had to apply to FEMA for aid. These seven counties included Cook and Du Page (northeast), and Carroll, Jo Daviess, Ogle, Stephenson, and Winnebago in the northwest storm area. By August 25, FEMA had received requests for aid from 17,653 households By August 25, FEMA had assessed losses totaling $9.4 million and had awarded $8 million. Several persons requesting assistance were refused with FEMA stating the residences were “livable” (Chicago Tribune, August 20).

By September 1 FEMA reported it had approved $60.9 million in aid and had already distributed $33 million (Chicago Tribune, September 7). After many loss uncertainty investigations, FEMA made delayed awards to complaining individuals (Chicago Tribune,

August 13). Also many persons sought state aid, and delivery of food stamps was delayed in most counties (Chicago Tribune, September 2). Massive lines of people were at several offices of the Illinois Department of Human Services in Cook County. The agency approved $2.4 million in disaster food aid for 5,690 Illinois households.

FEMA had distributed $75 million in disaster aid by September 3 (Chicago Tribune, September 3). More than 45,000 persons had applied for aid and the average package awarded was $3,000. Another battle between damaged areas and FEMA developed in October when FEMA refused to provide aid to public institutions (cities and county agencies) in Cook and DuPage counties (Chicago Tribune, October 22) to repair damaged streets and public infrastructure. FEMA claimed the total losses in the two counties (average loss per resident) were not high enough to meet the $3.23 per resident level set by FEMA. Although estimated losses were high in both counties (Cook=$14.6 million and DuPage=$935,000) their high populations kept the resident averages below the FEMA threshold. Governor Quinn appealed for a change but it was not made. The five other counties in the disaster declaration were given FEMA funding to repair damaged public institutions. Although these counties had less damage than Cook County, they had much lower populations and had an average above the FEMA limit of $3.23 per resident. FEMA had provided $278.7 million to private interests (households and businesses) in Illinois by October 22. Cook County got $266 million in responses to 125,000 requests for aid.

The U.S. Department of Agriculture identified seven counties in northwestern Illinois as disaster counties. Low interest loans were made available for farmers experiencing physical damages and production losses (FarmWeek, September 20).

The economic impacts included losses and costs. The losses included those to property ($105 million), to agriculture ($34 million), and those to transportation systems ($42 million). Losses totaled $181 million. A study of flood losses in the United States during 1949-2007 found the average loss from a flood was $79 million (Changnon, 2008), revealing that the July 2010 storm greatly exceeded the average.

The costs associated with responses to the July floods included federal relief ($320 million), state relief ($95 million), and local and state repairs to damaged infrastructure ($26 million). The FEMA payment was $320 million, the largest ever awarded to Illinois after a disaster (Chicago Tribune, November 26). Costs totaled $441 million. The losses and costs of the July storm totaled $620 million. The property losses ($181 million) ranked as the 13th most damaging storm event in Illinois during 1949-2010 after adjusting from inflation over time. (Changnon, 2010).

SUMMARY

A major rainstorm occurred in parts of northern Illinois from late on July 23 to late on July 24, 2010. Near record 24-hour rain amounts came from storms generated in an unstable frontal zone lying across northern Illinois. The heaviest rainfall, >10 inches, fell in Illinois' northwest and northeast corners. Maximum rainfall amounts for 3-, 6-, 12-, and 24-hour periods in Chicago rated as once in 100-year events at several raingages.

The dimensions of this rainstorm in the Chicago area were found to match the location of the heaviest historical rainstorms in northern Illinois (Vogel and Huff, 1977). This outcome is partially due to the urban and lake effects on the atmosphere which act to increase rainfall over Chicago (Changnon, 1980).

The heavy rains resulted in some flash flooding and all the rivers in northern Illinois had levels that were 4 to 7 feet above flood stages. Impacts of the excessive flooding in the northwest were largely to rural areas, whereas those in the northeast were to urban areas. Northeast area rains were heaviest in Chicago where values exceeded 100-year frequencies. The flooding did extensive damages to property (houses, buildings, and vehicles) in the Chicago area. Flooding losses in the northwest were largely to agriculture, and losses to transportation systems occurred in both areas. Trains were halted for 2-3 days and rail lines were washed out and train cars derailed.

The major costly impact was to property in Chicago and several suburbs. Losses totaled $181 million, and the highest cost was $320 million in federal aid. This FEMA aid to Illinois was larger than in any previous storm disaster to the state. The total losses and costs from the storm was $620 million

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Figure 1. Total storm rainfall for July 23-24, 2010.

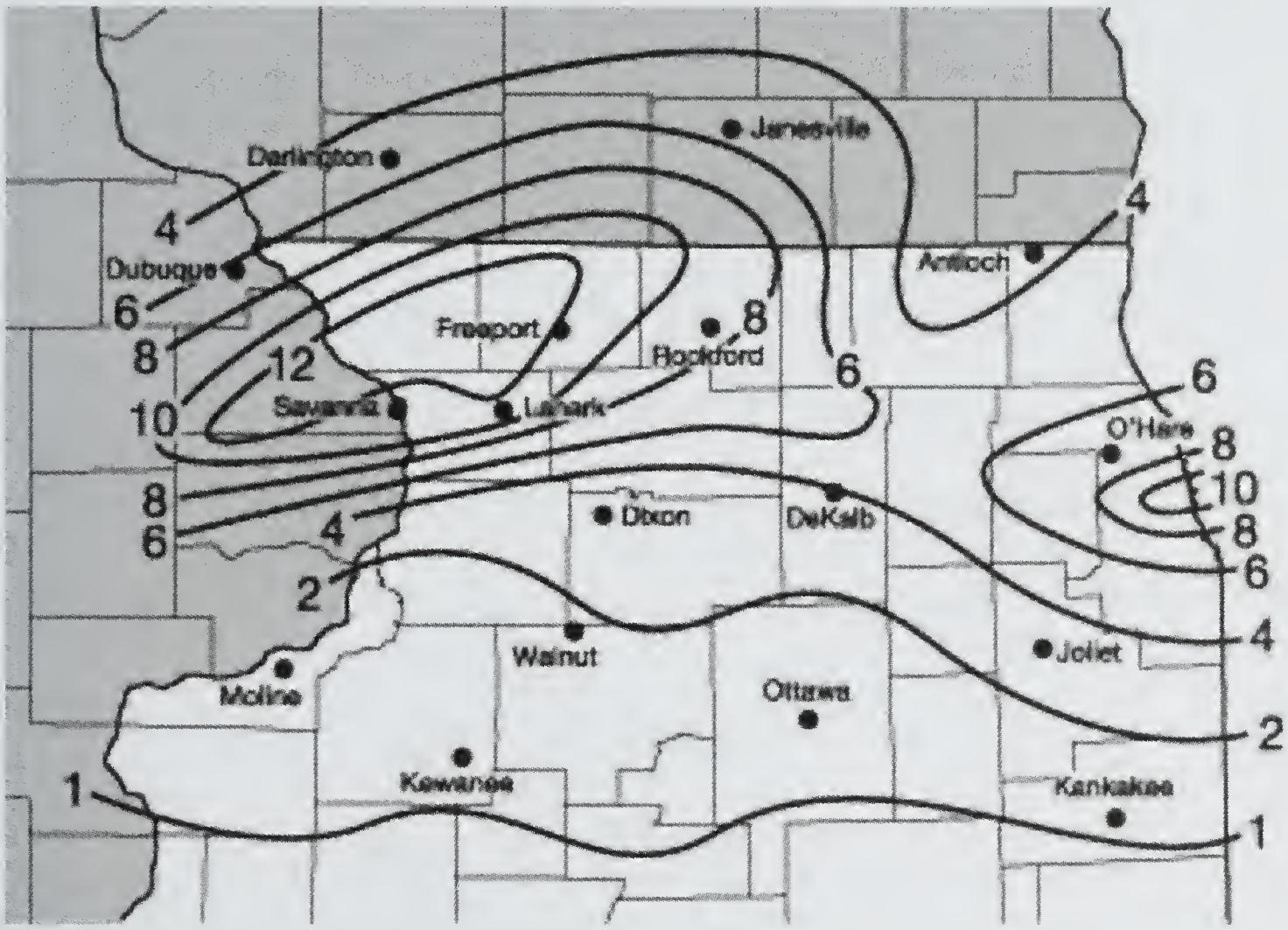
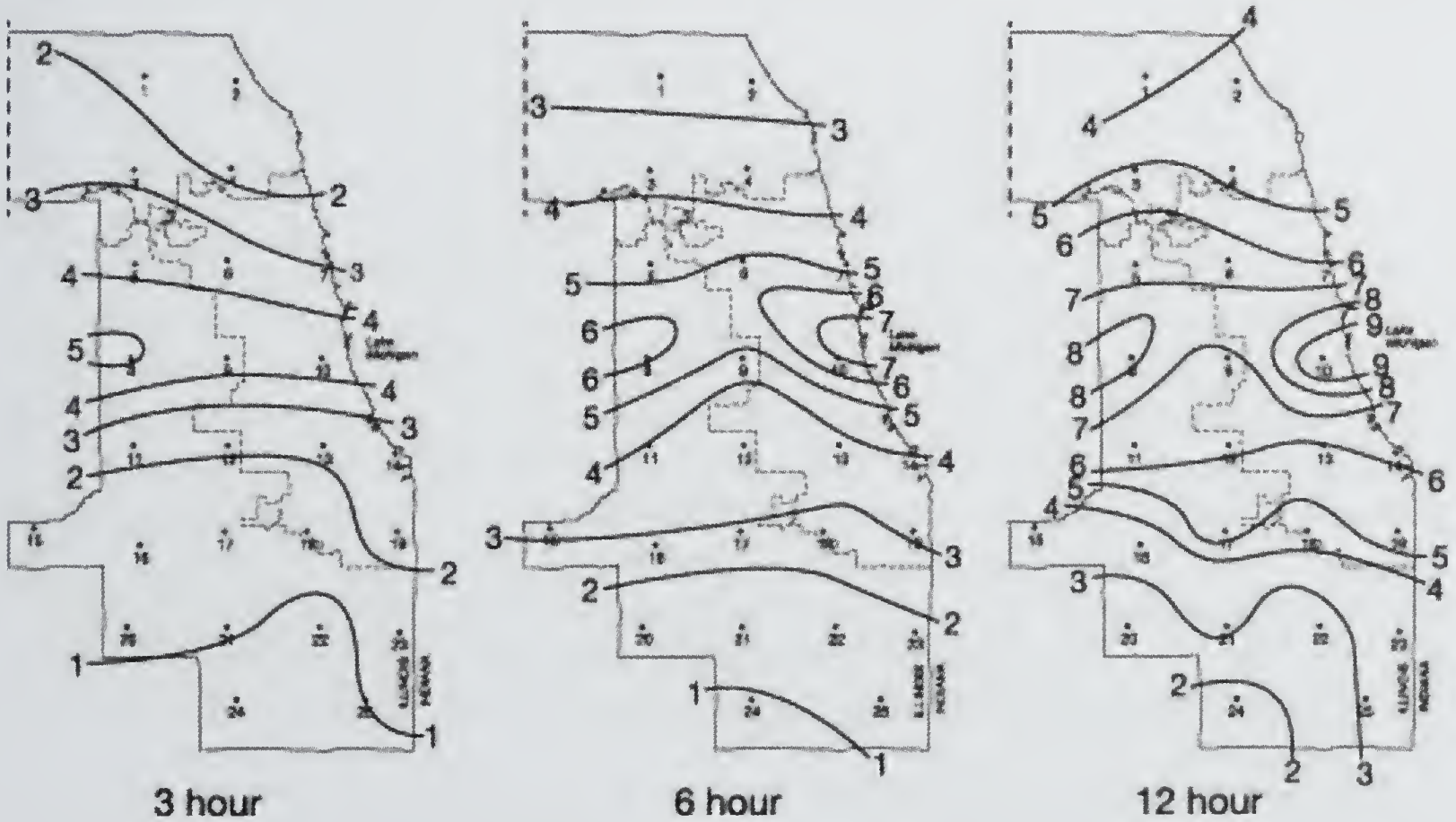


Figure 2. Maximum rainfall amounts for 3-, 6-, and 12-hours in the Cook County rain-gage network.



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Sampling Assemblages of Turtles in Central Illinois: A Case Study of Capture Efficiency and Species Coverage

Robert D. Bluett[1,2], Eric M. Schauber[3], Craig K. Bloomquist[3,4] and Douglas A. Brown[5]
[1]Illinois Department of Natural Resources, One Natural Resources Way
Springfield, IL 62702, USA
[2]Corresponding Author: Email: bob.bluett@illinois.gov
[3]Cooperative Wildlife Research Laboratory, Department of Zoology, and
Center for Ecology, Southern Illinois University, Carbondale, IL 62901, USA
[4]Current address: 3939 Highland Avenue, Downers Grove, IL 60515, USA
[5]Illinois Department of Natural Resources, 1660 West Polk, Charleston, IL 61920, USA

ABSTRACT

Low and variable rates of capture are chronic problems in chelonian studies. We conducted a pilot study to evaluate protocols for future inventories of turtles in Illinois by comparing capture efficiency and species coverage for 2 devices (hoop net and cage trap), baits (fresh and day-old fish), habitats (lentic and lotic) and time periods . We accrued 402 captures of 378 individuals representing 7 species. At Sanganois State Fish and Wildlife Area (Sanganois), hoop nets produced more captures of more species (n = 231; 6 species) than cage traps (n = 119; 4 species). Statistical tests were equivocal for a reach of the Sangamon River, where both devices had 26 captures but hoop nets detected more species (n = 6) than cage traps (n = 3). At Sanganois, catch per unit effort varied with sampling session (time) and freshness of baits; one measure of species coverage varied with session. Results helped us make informed decisions about protocols for future inventories.

INTRODUCTION

Many ecological studies rely on captures of animals to describe demographic traits of a population or assemblage. Valid results hinge on capturing adequate and representative samples (McDonald 2004). Doing so can be especially challenging during studies of turtles (Cagle 1942, Plummer 1979). One reason is that processes affecting dynamics of a population or assemblage often operate at geographic scales larger than those which can be sampled effectively (Burke et al. 1995). Heterogeneous rates of capture or detection pose another common problem (Boulinier et al. 1998, Koper and Brooks 1998, Link 2003, Royle 2006). For example, inferences about sex ratios are misleading if one group is captured preferentially (Ream and Ream 1966). Such findings make it difficult to assess broad paradigms or risks with confidence (Gibbons 1970, Dodd 1997, Holmes 2001).

Efficiency and bias are difficult to evaluate quantitatively. The most informative approach requires direct comparisons of metrics derived from sampling to those of

known populations (Bayless 1975). Circumstances that allow such comparisons are rare (Burgin et al. 1999). Therefore, most evaluations are based on relative comparisons of rates of capture for 2 or more methods of collection, sites, time periods or other potential sources of variability (e.g., Ream and Ream 1966, Frazer et al. 1990, Jensen 1998, Thomas et al. 1999, McKenna 2001, Browne and Hecnar 2005, Gamble 2006, Wallace et al. 2007, Thomas et al. 2008, Nall and Thomas 2009, Sterrett et al. 2010). These comparisons do not speak to representativeness of a sample, but they allow researchers to test hypotheses about equal probabilities of capture that are useful for evaluating efficiency and, depending on the design of a study, finding violations of assumptions to infer the presence of bias (e.g., Lindeman 1990, Olivier et al. 2010).

Pilot studies are a good way to evaluate protocols so shortcomings can be identified and addressed proactively in the design of full-fledged investigations (Green 1979, Frazer et al. 1990, Mazerolle et al. 2007). We used this approach to improve protocols for inventories of turtles in Illinois (e.g., Major et al. 2009). We did so by evaluating capture efficiency and species coverage for 2 devices (hoop net and cage trap), baits (fresh and day-old fish), habitats (lentic and lotic) and time periods.

STUDY AREA

The study was conducted at 2 sites in central Illinois. Both occur in the Lower Sangamon River Valley, which drains approximately 11,849 km^2 (Illinois Department of Natural Resources 2003). Sanganois State Fish and Wildlife Area (Sanganois) encompasses 3,835 ha located at the confluence of the Illinois and Sangamon rivers in Cass and Mason counties. Major habitats include forested wetland (2,159 ha), lake (665 ha) and scrub-shrub (354 ha; Yetter et al. 1999). We chose Barkhausen Waterfowl Refuge as a focal area within Sanganois, and, more specifically, that part of the refuge that lies on the tail (west) end of Wilcox Lake (first station 40.06638°N, 090.26012°W; WGS 84). We measured water temperatures at the surface with a digital thermometer; temperatures varied from 25.9-29.0°C. River stages on the Illinois River (as reported by the State Journal Register for Beardstown, IL) were greater during the first session (3.149-3.286 m) than second (2.963-2.987 m). Substrates varied from fine silt to sand. Past sampling (in an area that included but was not limited to our study site; R. D. Bluett, unpublished data) indicated that turtles were abundant with a relatively diverse assemblage composed of Red-eared Slider (*Trachemys scripta*; later referred to as slider for brevity), Spiny Softshell (*Apalone spinifera*), Painted (*Chrysemys picta*), Snapping (*Chelydra serpentina*) and Eastern Musk (*Sternotherus odoratus*) turtles. A single Ouachita Map Turtle (*Graptemys ouachitensis*) was captured in the study area on 1 occasion during past sampling.

Our other study area was a reach of the Sangamon River located southeast of Petersburg in Menard County. Most of the area we sampled (first station 39.98006°N, 089.83537°W; WGS 84) was bordered by Lincoln's New Salem State Historic Site (New Salem). The river is incised deeply (e.g., 2-4 m), with steep banks in most places. Substrates include clay, fine silt, sand, and sand mixed with gravel. As at Sanganois, basking sites, mainly downed trees and logjams, were common in the study area. River stages on the Sangamon River (at Oakford, IL) were similar during both sessions (1.003-1.143 m). Water temperatures varied from 24.7-27.7°C. Past sampling (in an area that included but was not limited to our study site; R. D. Bluett, unpublished data) indicated that turtles were

less abundant at New Salem than Sanganois and included a slightly different assemblage composed of *T. scripta*, *A. spinifera*, *C. picta*, *C. serpentina*, *G. ouachitensis* and Smooth Softshell (*Apalone mutica*).

METHODS

We compared capture efficiency and species sampling by a wire-mesh (2.54 cm x 2.54 cm, 14-gauge) cage trap (Pied Piper Animal Traps, 445 Garner-Adell Rd., Weatherford, Texas, USA) to that of a hoop net. The cage trap measured 43.18 cm x 43.18 cm x 91.44 cm, had a single wire throat at the front, and a holding compartment at the back accessed by turtles through 2 one-way doors. Hoop nets were made locally by a commercial fisherman. They had 3 hoops (60.96 cm in diameter), 3.81-cm-mesh, and a single flat (sometimes referred to as "Arkansas style") throat.

We conducted 2 trapping sessions at each site. A session consisted of 4 consecutive trap-nights, each of which was approximately 24 hours in duration. Sessions at Sanganois started on 25 June and 16 July 2007; those at New Salem began on 30 July and 20 August 2007. We used a cross-over design to reduce potential sources of bias. The first station (i.e., trap location) at each site was located a random distance (range 0-99 m) from a predetermined starting point. At the beginning of each session, we flipped a coin to determine which type of device to place at the first station. Thereafter, we alternated device types at 130-m intervals along the shoreline, deploying 10 of each type at Sanganois and 6 of each at New Salem.

Distances were determined with a hand-held Global Positioning System (Garmin International, Inc., Olathe, Kansas, USA). Execution was straightforward at Sanganois, where water depths along the shoreline were somewhat uniform, allowing us to place either device with at least two thirds of the throat underwater and the back of the net or cage at least 7.6 cm above the waterline to allow turtles to breathe. Depths were more variable at New Salem, so we chose 1 bank or the other depending on suitability of conditions at locations 130 meters apart. After 2 trap-nights, we switched devices so that each station accrued equal amounts of effort with each device during each session. We censored data from devices that had been tampered with and were no longer fully operational when checked.

We baited devices with 400-600 g of fresh frozen fish (*Cyprinus carpio*, *Ctenopharyngodon idella*, *Hypothalmichthys molitrix*, *H. nobilis*) suspended underwater from the back of the cage or third hoop in a nylon-mesh bag made from drain-tile sleeve (DrainKnit Filtration Barrier Fabric, Dickson Industries, Inc., Des Moines, Iowa, USA). To avoid bias, we mixed bagged baits in a cooler and drew them as sets were made. We replaced baits with fresh ones after 2 trap-nights. Based on past experience, we anticipated that some baits would be consumed entirely by turtles during the first trap-night. Recognizing that freshness can affect capture success for some species (Lagler 1943, Ernst 1965), we cached extra baits underwater near the study area and replaced missing day-old baits with these extra baits when we checked devices after the first and third trap-nights. Captured turtles were marked by shell notching (Cagle 1939), measured with a "bump board" commonly used for studies of fishes (carapace length to nearest 0.5 cm), and sexed based on secondary sex characteristics (Ernst et al. 1994).

Statistical tests followed McCulloch and Searle (2001). Data for analyses of catch per unit effort (CPUE) and species coverage included recaptures. We used a mixed Poisson model to test for differences in CPUE between devices, bait ages (1- vs. 2-day-old), and sessions (categorical fixed effects, including pairwise interactions), treating stations as independent experimental subjects (random effects). The response variable was the total number of turtles (of all species) captured at a given day and station. Because CPUE was clearly lower at New Salem than Sanganois, we analyzed data from each site separately. Poisson regression assumes a linear relationship between the log number captured and explanatory variables, so back-transformed estimates provide multiplicative effect sizes. Interactions were dropped from the model if $P > 0.1$, in order of highest P-value.

We used 2 complementary analyses to test for differences in species coverage between devices (i.e., the ability of different devices to effectively sample the range of species present). Because sliders were clearly dominant in the captured sample, we first simply tested for differences in the proportion of captures composed of other species (i.e., not sliders), using mixed-model logistic regression. For this analysis, session, bait, and device (and their pairwise interactions) were included as categorical fixed effects, and stations were treated as independent subjects. Effect size estimates from logistic regression were converted to odds-ratios.

The second analysis of species coverage examined the relationship between sample size (no. turtles captured) and the number of species observed, known as the rarefaction curve (Gotelli and Colwell 2001). The steeper this relationship, the greater species coverage is provided by a given number of captured turtles. For this analysis, we used mixed-model Poisson regression with the number of species captured as the response variable. Because instances of 0 or 1 captures were uninformative (i.e., only 0 or 1 species can be observed, respectively), we only included instances where ≥2 turtles were captured. The model included the number of captures minus 1 as the primary explanatory variable, and intercepts were fixed at 0 [i.e., log(# species) = 0 if no. captures -1 = 0]. The slope versus captures -1 was allowed to vary randomly among stations, and we tested whether slope differed with session, bait age, and device.

RESULTS

We censored 6 trap-nights because of tampering. At Sanganois, each device was deployed for 40 trap-nights during the first session and 38 during the second, accruing total efforts of 78 trap-nights for cage traps (1836 hr) and the same number of trap-nights for hoop nets (1842 hr). At New Salem, each device was deployed for 23 trap-nights during the first session and 24 during the second, accruing total efforts of 47 trap-nights for cage traps (1113 hr) and the same for hoop nets (1109 hr). Day-old baits were replaced with the same at 6 sets because no bait remained when devices were tended after the first and third trap-nights of a session; 4 of these devices contained ≥1 turtle when sets were checked.

We recorded 402 captures of 378 individuals (Table 1). Original captures of males and females at all sites and for all combinations of gear and bait were similar for *T. scripta* and *C. picta* but not *A. spinifera* (Table 2); we deemed sample sizes too small for

comparisons of other species. Median carapace lengths were similar for sexes of *C. picta* and *A. spinifera* but not *T. scripta*.

Catch per unit effort was greater at Sanganois (2.24) than New Salem (0.55) for all species and both devices combined. Cage traps failed to detect 1 species captured in hoop nets at Sanganois (*C. serpentina*) and 3 at New Salem (*C. serpentina*, *G. ouachitensis*, *A. mutica*). Recapture rates for all species and both devices combined were greater at New Salem (17.3%) than Sanganois (4.3%). Most recaptures occurred in hoop nets at Sanganois (86.7%) and New Salem (77.8%). Only *T. scripta* was recaptured in cage traps; 4 species were recaptured in hoop nets.

CPUE. The final model for Sanganois included only main effects of session, bait, and device (all $F_{1,19} > 12.4$, $P < 0.002$). At Sanganois, fresh bait increased CPUE nearly 3-fold relative to 2-day-old bait (2.94 vs. 1.05 turtles/day, respectively), and CPUE was approximately 2-fold higher for hoop nets than cage traps (2.38 vs. 1.30 turtles/day, respectively) and for the second than the first session (2.58 vs. 1.20 turtles/day, respectively). For New Salem, interactions with session were dropped from the model and no remaining variables yielded $P < 0.05$. Confidence intervals for the main effects at New Salem were wide, however, and generally overlapped the estimated bait and device effects for Sanganois (Fig. 1).

Species coverage. The final model for Sanganois included no interactions, and the odds of a captured turtle being a non-slider were estimated to be 8.80-fold higher (95% CI: 2.78-27.87) for hoop nets than for cage traps ($F_{1,18} = 15.75$, $P < 0.001$). Bait age had no apparent effect on species coverage ($F_{1,16} = 0.21$, $P = 0.65$), and there was marginal evidence for a session effect ($F_{1,16} = 3.89$, $P = 0.066$) at Sanganois. For New Salem, no main effect or interaction was significant (all $P > 0.17$), but the estimated odds-ratio between devices (2.10-fold) had a wide 95% confidence interval (0.37-11.80) that included the Sanganois estimate.

For Sanganois, the slope of log (no. species) vs. captures -1 was greater for hoop nets than cage traps (0.097 vs. 0.011) and greater in the early session (both $F_{1,49} > 10$, $P < 0.002$), but we detected no effect of bait age ($F_{1,49} = 1.7$, $P = 0.20$) on the slope.

DISCUSSION

We do not know the true composition of assemblages on our study areas, but can make some reasonable comparisons to museum records and other sampling efforts. Twelve of 15 species of aquatic turtles that occur in Illinois have been documented in the region (Phillips et al. 1999). The lone record for 1 species (*Macrochelys temminckii*) is suspect (Moll 1988). Three others (*G. geographica*, *G. pseudogeographica*, *Kinosternon flavescens*) are not likely to occur in habitats we sampled (Ernst et al. 1994), but their presence cannot be discounted completely. At worst, hoop nets detected 64% of species known to occur in the region. At best, they detected 87% of species in the region (i.e., excluding 3 species that prefer habitats other than those we sampled). At Sanganois, hoop nets were almost 9 times as likely to capture a non-slider as cage traps. No significant differences occurred at New Salem, but samples were small and trends were similar [e.g., hoop nets captured more species than cage traps during both the first (4 vs. 3) and second

(5 vs. 3) sessions]. We concluded that hoop nets were more effective than cage traps for detecting species that occur in central Illinois and recommended dropping cage traps from consideration as a sampling device for future inventories.

Anecdotal reports suggest that fresh baits are better than putrid ones (e.g., Lagler 1943, Legler 1960, Plummer 1979). Captures at Sanganois supported these observations, with fresh baits outperforming day-old baits by nearly 3:1. Implications for future inventories were unclear because we did not observe any effects of baits on species coverage. To be on the safe side, we chose to standardize protocols for future inventories by requiring daily changes of baits. We recommend the same conservative approach for other studies that use baited traps and methods of analyses that are sensitive to heterogeneous rates of capture. For example, waning attractiveness of baits could cause the appearance of time or behavioral effects (i.e., trap shyness) in analyses of data from capture-recapture and occupancy studies.

We did not recapture enough turtles of any species to compare robust estimates of abundance to catch per unit effort. Use of CPUE requires narrow limits on its application, including assumptions of closure and equal catchability (Lancia et al. 1996, Maunder et al. 2006). Differences between sessions at Sanganois implied violation of 1 or both of these assumptions. We speculated that high water levels during the first session at Sanganois contributed to differences in CPUE by allowing turtles to exploit abundant food sources in flooded margins of the lake, thereby making our baits less attractive than during the second session when these conditions did not exist. We concluded that water level is a good candidate for monitoring as a covariate during studies of the demography of turtles in or near lotic systems. Although CPUE has been used as an index of abundance in chelonian studies (e.g., Aresco 2009), we decided that data we planned to collect during future inventories would not suit this purpose because of the likelihood of violations of assumptions caused by protocols (i.e., multiple observers targeting multiple species during multiple years and long periods of time within years) and varying environmental conditions.

Few of our findings can be applied directly to other research because our study was tailored to specific needs, study areas were chosen opportunistically and assemblages differ in other areas. However, some aspects of our study are relevant in a broader context. Waning effectiveness of baits could be a widespread problem in chelonian studies because few researchers change baits daily. Unlike most studies of efficiency and bias, we used an efficient design to evaluate multiple variables and estimated the magnitude of effects (i.e., odds ratios) to interpret outcomes readily (Hayek 1994). Mostly, our findings demonstrate the value of *a priori* studies for choosing effective survey methods, reducing biases caused by protocols, and identifying covariates or other statistical tools that help to cope with variable rates of capture (e.g., Amstrup et al. 2005, MacKenzie et al. 2006, Olivier et al. 2010).

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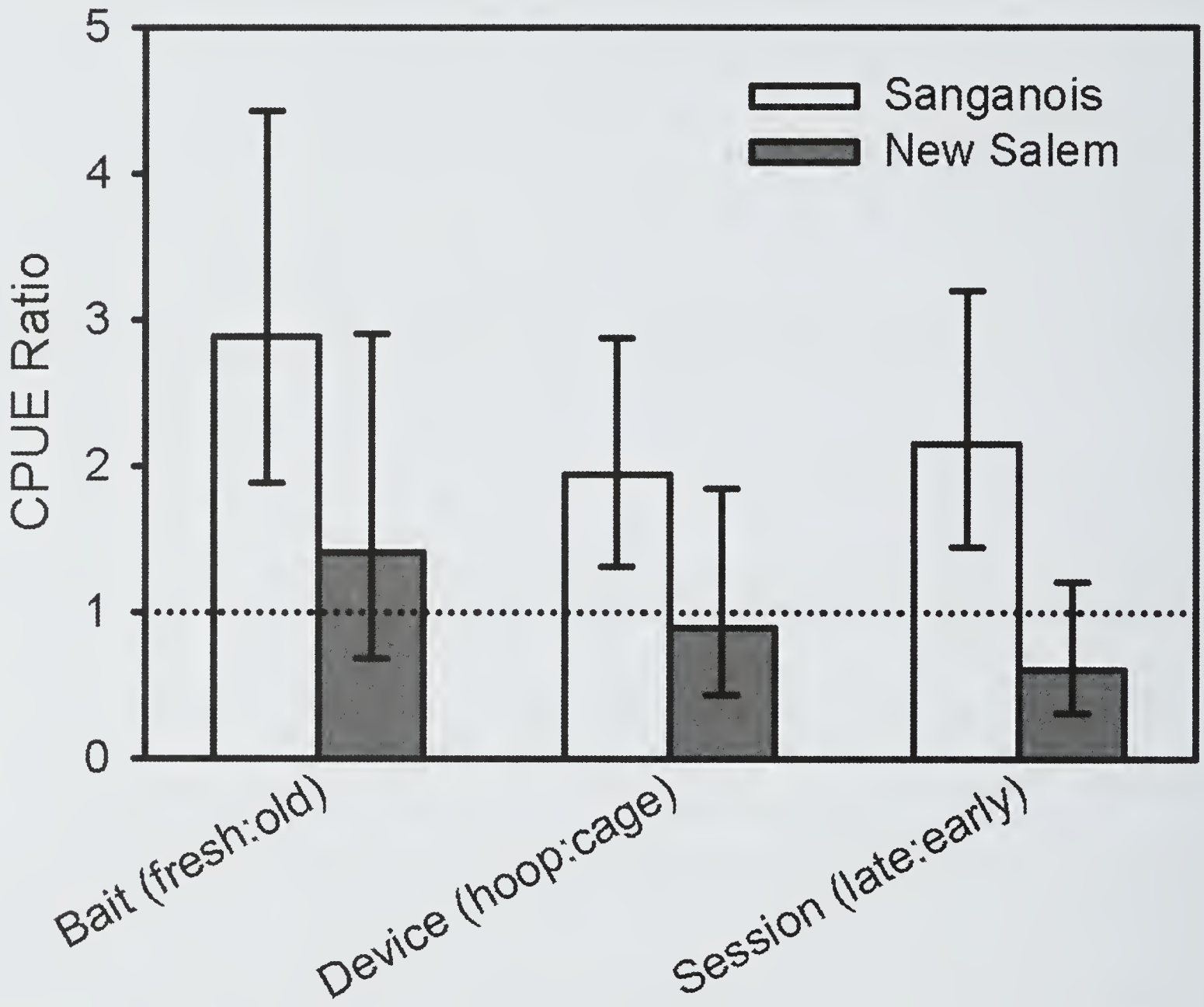
Table 1. Captures (including recaptures) of freshwater turtles in cage traps and hoop nets at two study areas in central Illinois, 2007.

	Sanganois				New Salem			
	Session 1		Session 2		Session 1		Session 2	
Species	Cage	Net	Cage	Net	Cage	Net	Cage	Net
Trachemys scripta	41	50	74	129	14	8	4	4
Apalone spinifera	1	13	0	13	1	0	2	3
Chrysemys picta	0	5	2	12	2	2	3	1
Chelydra serpentina	0	1	0	2	0	4	0	1
Sternotherus odoratus	0	4	1	2	0	0	0	0
Graptemys ouachitensis	0	0	0	0	0	1	0	0
Apalone mutica	0	0	0	0	0	0	0	2
Combined	42	73	77	158	17	15	9	11

Table 2. Sexes and sizes of three species of turtles captured at two study areas in central Illinois, 2007.

				Carapace length (measured to nearest 0.5 cm)			
	Sex (no. individuals)			Male		Female	
	Male	Female	Unknown	Median	Range	Median	Range
Chrysemys picta	13	13	0	14.0	10.5-16.5	14.25	12.5-17.5
Trachemys scripta	156	147	3	16.5	9.5-23.0	18.50	7.0-26.0
Apalone spinifera	17	7	0	18.5	14.0-43.0	18.25	16.5-25.0

Figure 1. Estimated multiplicative effects, presented as estimated ratios (*y*:1) with 95% confidence intervals, of bait age (1- vs. 2-days old), capture device, and session on catch per unit effort (CPUE) in capturing aquatic turtles in two Illinois study areas, June-August 2007. The dotted horizontal line represents a 1:1 ratio, indicating no effect.



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Detection Bias in Noninvasive Track Surveys of Mammalian Predators in Illinois

Edward J. Heske[1], Torrey W. Rodgers[1], and Timothy R. Van Deelen[2]
[1]Illinois Natural History Survey, 1816 South Oak Street, Champaign, Illinois 61820
[2]Department of Wildlife Ecology, University of Wisconsin, Madison, Wisconsin 53706

ABSTRACT

We compared the species of mammalian predators detected by track surveys using sooted track plates, natural soil, and fine sand as track-collecting substrates. Some species, such as coyotes, foxes, and bobcats, were detected less frequently by track plates than by more natural substrates. In contrast, raccoons and opossums did not show substrate avoidance. Additional data from camera traps and snow tracking in one study did not reveal any species of mammalian predators not detected by sand stations. Potential sampling bias due to responses of different species to tracking substrate or baits and lures used as attractants should be kept in mind when designing predator surveys.

INTRODUCTION

Knowledge of presence-absence and relative abundance of mammalian predators is important to biologists and managers because these species often play a key role in ecosystem processes (Gittleman and Gompper 2005, Roemer et al. 2009). Because mammalian predators can be elusive and occur at low population densities, direct survey methods are challenging. Capture methods also are time consuming and invasive (Barea-Azcon et al. 2007). Thus, various methods have been developed to detect mammalian predators noninvasively. Of these, the most simple and economical are those using baited track stations to lure animals and capture their tracks for identification (Linhart and Knowlton 1975, Connor et al. 1983, Taylor and Raphael 1988). Here, we compare 3 such methods using data from 2 studies in central and southern Illinois, and discuss potential benefits and biases of each.

Mammalian predators vary considerably in body size, diet, and behavior. As a consequence, survey techniques may be biased in their ability to detect different species (Gompper et al. 2006). For example, in 1 study in Illinois, coyotes (*Canis latrans*) and foxes (red foxes, *Vulpes vulpes* and gray foxes, *Urocyon cinereoargenteus*) were rarely detected, and bobcats (*Felis rufus*) were not detected by sooted track plates although they were commonly seen (e.g., coyotes) or known to occur (e.g., bobcats) in the study area (Heske 1995). Some animals may be wary of and avoid stepping on foreign tracking surfaces (Gompper et al. 2006). Additionally, track stations often use bait as an attractant, and different species may react differently to different bait types.

We conducted track surveys of mammalian predators during 2 studies designed to compare species detected by different methods: sooted aluminum track plates (Taylor and Raphael 1988), track stations using a substrate of imported sand (Connor et al. 1983), and track stations using a substrate of naturally occurring soil cleared of debris. We also used remote camera traps and snow-track surveys at one site to determine if these methods detected any species not detected by our track stations. By conducting multiple noninvasive survey techniques simultaneously at each site, we sought to determine which methods were most effective at detecting a range of mammalian predators, and which methods contained biases leading to the detection of some species but not others. Although tracks of additional species such as squirrels (*Sciurus niger* and *S. carolinensis*), chipmunks (*Tamias striatus*), mice (mostly *Peromyscus* sp.), deer (*Odocoileus virginianus*), various birds, frogs, toads, and turtles were observed, we focused our analysis on mammalian predators.

METHODS

Cache River, 1994

We conducted surveys along 14 transects in the Cache River area of southern Illinois during May-July 1994. Five 1-km transects were set in upland or bottomland forest interior (>300 m from forest edge) and three 1-km transects were set under forest canopy but <10 m from forest edge in and around the Cache River Natural Area in Johnson County, IL. Additionally, six 500-m transects were set in riparian forest along the Cache River in Johnson and Pulaski counties. Each transect consisted of 5 track stations (1-km transects) or 3 track stations (500-m transects) spaced 250 m apart. At stations 1, 3, and 5 on 1-km transects, and stations 1 and 3 on 500-m transects, we placed sooted track plates consisting of two 1 m x 0.5 m sheets of 0.32-gauge aluminum coated with soot from a kerosene torch. The two plates were set side-by-side on a cleared, level, 1-m^2 area with an open tin of sardines in soybean oil in the center as bait. At stations 2 and 4 (1-km transects), and at station 2 (500-m transects), we made track stations using the natural soil as substrate by clearing a 1-m diameter circle of debris and softening and smoothing the soil with an iron rake. We then excavated a 10-cm deep by 6-cm wide hole in the center of the circle with a garden bulb planter, and placed approximately 15 cc of predator lure (Power River Paste, O'Gorman Enterprises, Inc., Broadus, MT) into the hole, which was then loosely stuffed with vegetation. Finally, we misted the hole and surrounding ground with red fox urine. While setting all stations, we wore rubber boots and gloves to reduce human scent. Each transect was set and checked for 5 consecutive days in May, June, and July, for a total of 15 survey nights per transect. Soil was raked and smoothed, and bait and track plates were replaced as needed during each check. Data were recorded as each carnivore species that left tracks at a station between successive checks.

Middle Fork Fish and Wildlife Area, 1995

We conducted surveys along 15 transects at the Middle Fork Fish and Wildlife Area (MFFWA) in Vermilion County, IL in August and September 1995. Transects were set under forest canopy <5 m from forest edge. Each transect was 500 m long and contained 3 stations spaced 250 m apart. At one station, we placed sooted aluminum track plates as previously described. At a second station, we cleared a 1 m x 2 m area of vegetation and

raked it smooth, and then covered it with fine sand to a depth of 1-2 cm. At a third station, we placed a Trailmaster automatic infrared camera trap (Model TM 1500, Goodson and Associates, Lenexa, KS). The infrared emitter and receiver were set 3 m apart, with the beam located 18 cm above ground level. All stations were baited with a piece of raw chicken (neck, back, gizzard). Order of station type (track plates, sand, camera) along each transect was randomly stratified such that each station type was in the middle on 5 transects. Transects were checked on 3 consecutive days during 1 period in August and 1 period in September, for a total of 6 survey nights per station. Track plates were replaced, sand was raked smooth, and bait was replaced as necessary. Data from cameras were recorded as number of nights that photos were taken of each species, regardless of number of photos or individuals in each photo, to be comparable to track data and because individuals of the species detected could not be distinguished in photos. In addition, we walked each transect on a single day in December following a snowfall and recorded each species for which we found snow tracks along each transect.

We evaluated substrate bias by comparing detections on track plates and either natural soil (Cache River) or fine sand (MFFWA) to the number expected if detection was random in each study using chi-square tests. We evaluated each study separately because of their different substrates and baits, and pooled data for coyotes, foxes, bobcats, domestic cats (*Felis catus*), and long-tailed weasels (*Mustela frenata*) into a single category (Other carnivorans) because of small sample sizes for each species.

RESULTS

In our combined surveys using sooted track plates (n = 630 survey nights), natural soil track stations (n = 330 survey nights), sand track stations (n = 90 survey nights), camera trap stations (n = 90 survey nights), and snow tracking (7.5 km of transect walked), we detected 7 species of mammalian predator: Virginia opossums (*Didelphis virginiana*), raccoons (*Procyon lotor*), foxes, coyotes, bobcats, domestic cats, and long-tailed weasels. We could not distinguish tracks of red foxes from those of gray foxes in most cases, so we pooled these as "fox." Bobcat tracks were only detected in southern Illinois, but bobcats were likely not present in MFFWA at the time of our study. In contrast, domestic cats were detected only at MFFWA, where they were regularly observed. In previous live-trapping at MFFWA, domestic cats that were captured appeared scruffy and aggressive (E. J. Heske, pers. obs.). We therefore consider domestic cats at MFFWA to be either feral or free-roaming farm cats.

Sooted track plates detected primarily raccoons and opossums, and also detected weasels on 3 occasions in MFFWA; they did not detect foxes, coyotes, or bobcats (Tables 1 and 2). Soil track stations detected all species except weasels (which also were not detected by track plates in the Cache area in 1994), and sand track stations detected all species but bobcats (which likely were not present at MFFWA in 1995). Camera traps at MFFWA in 1995 detected raccoons and opossums, but no other wild mammalian predators. Snow tracking detected all species at MFFWA detected by the other methods, with the exception of opossums. It is likely that activity by opossums was curtailed during the cold spell associated with the snow event; opossum tracks have been observed in snow at MFFWA on other occasions (E.J. Heske, pers. obs.).

Raccoons were detected more often by track plates than by soil track stations in the Cache area ($\chi^2_1 = 21.66, p < 0.001$), as were opossums ($\chi^2_1 = 48.16, p < 0.001$; Fig. 1A, Table 1). In contrast, foxes, coyotes, and bobcats were only detected by soil track stations in 1994 ($\chi^2_1 = 15.0, p < 0.001$; Table 1), although the number of detections per survey night was low (Fig. 1A). At the MFFWA in 1995, raccoons were more readily detected by cameras than either type of track station (Fig. 1B), but detections of raccoons by track plates and sand stations did not differ ($\chi^2_1 = 1.0, p = 0.317$, Table 2). In contrast, opossums were more readily detected by track plates and sand stations than by cameras (Fig. 1B), but like raccoons, detections of opossums by track plates and sand stations did not differ ($\chi^2_1 = 0.62, p = 0.431$; Table 2). Foxes and coyotes were only detected by sand stations, domestic cats were detected by both sand stations and cameras, and long-tailed weasels by both types of track stations (Table 2), but all at low frequency (Fig. 1B). Detections of our pooled category, Other carnivorans, did not differ between track plates and sand stations ($\chi^2_1 = 2.28, p = 0.131$), however, sample size was small and weasels appeared to respond differently to substrate than the canids and felids. Detections of foxes, coyotes, and domestic cats at MFFWA were similar to detections of foxes, coyotes, and bobcats in the Cache area, and detections by track plates and sand stations differed ($\chi^2_1 = 7.0, p = 0.008$) when only these canids and felids were considered.

DISCUSSION

The type of substrate used to collect tracks of mammalian predators can bias detection, as suggested by others (e.g., Heske 1995, Gompper et al. 2006). In our comparisons, sooted aluminum track plates did not detect canid species such as coyotes or foxes, nor did they detect bobcats or domestic cats. These species may be wary of foreign substrates, and thus avoid stepping on the aluminum surface. Sooted track plates readily detected raccoons and opossums, and to a lesser extent, weasels, however. Sooted track tubes were used to survey for weasels in southern Illinois by Richter (2005), for example. Raccoons and opossums often exploit anthropogenic food resources and acclimate to human disturbance (e.g., Prange et al. 2004); unfamiliar substrates may not deter these species. It would be interesting to determine if coyotes and foxes acclimated to urban settings lose their wariness of such substrates as well. Advantages of sooted track plates are that they yield very clear tracks, which can be "lifted" with tape for future identification by more experienced observers, and they can be moved and reused in multiple locations (Taylor and Raphael 1988). Several pre-sooted track plates can be carried into remote areas in specialized backpacks, whereas bags of sand for sand stations (10 – 20 kg/station) are difficult to transport away from roads.

The natural soil track stations used in our 1994 surveys mimicked food caches of foxes (Schwartz and Schwartz 1981), and were similar to bait stations used by fur-trappers. Thus, substrate and bait type were confounded in this comparison. Sardines are an attractive bait for raccoons and opossums, which may have been less attracted to the commercial carnivore lure used at the natural soil stations. It is clear, however, that potential biases in responses of predators to both substrate and bait should be considered when interpreting results of track station surveys. Natural soil track stations have the advantage of using a substrate familiar to the species being surveyed and do not require the import of outside material other than bait. Tracks at natural soil stations can be difficult to read and identify, however, and are easily affected by adverse weather conditions.

Sand track stations detected more species of mammalian mesopredators than either track plates or cameras in our 1995 study, and detected all the species confirmed as present at MFFWA in our snow-tracking survey. Adding a small amount of mineral oil to fine sand before spreading it as a substrate also improves clarity of tracks (Hoffman and Heske 2003). We also recommend using a commercial attractant such as fatty acid scent rather than food baits at sand stations, as food baits degrade quickly in hot, humid weather, attract insects, and tracks at stations can be obliterated when species such as raccoons or opossums consume the bait on the station and forage through the sand for more (E. J. Heske, pers. obs.; Cottam et al. 2009). Sand stations cannot be moved like sooted track plates, however, they can be reused by smoothing the sand and re-baiting, and can be left in place for longer periods of time to habituate animals. Sand stations have been used in a variety of studies (e.g., Connor et al. 1983, Heske et al. 1999, Cottam et al. 2009), and our comparison shows that they introduce less bias in species detection than sooted track plates. The widespread use of similar track stations for detection and monitoring of carnivorans by wildlife or natural resource agencies is supported by our data.

Trailmaster camera traps used in our 1995 study detected raccoons and opossums, but failed to detect foxes, coyotes, or weasels. More extensive use of camera traps at MFFWA in 1996 (Heske et al. 1999) also added fox squirrels, white-tailed deer, domestic cats, domestic dogs, striped skunks (*Mephitis mephitis*), and humans to the list of mammals photographed, but recorded only a single photograph of a coyote in contrast to 11 records of coyote tracks at sand stations on the same transects (E. J. Heske, unpublished data). Coyotes and foxes may be wary of approaching cameras (Hernandez et al. 1997, Gompper et al. 2006), and smaller species such as weasels may be missed by cameras due to their size (Gompper et al. 2006, Tobler et al. 2008). Camera traps have many advantages; for example, they can be left in place for long periods of time, are less susceptible to inclement weather, and can provide information on individual identities of some detected species. The cameras we used in our surveys were early-generation technology, and left in place for only a short period of time. Significant advancements in camera-trap technology have been made since our study, and numerous studies have since reevaluated their effectiveness (Silveira et al. 2003, Gompper et al. 2006; Tobler et al. 2008). Neilsen et al. (2009) effectively used camera surveys to detect coyotes, red and gray foxes, and bobcats throughout southern Illinois. We include our camera data here primarily to show, along with the snow-tracking data, that the species detected in our track surveys were representative of the species present at MFFWA at the time of our study (i.e., cameras did not detect additional species missed by track surveys).

Our study confirmed the suspicion that sooted track stations can underestimate detection of some mammalian predators, particularly canids and felids (Heske 1995, Gompper et al. 2006). Natural soil track stations detected these predators much better than track plates, however, sand stations yielded tracks that were often clearer and easier to identify. The relationship between counts from track stations and population density has been questioned by some (e.g., Smith et al. 1994), and relationships are likely non-linear (MacFarland 2009). Our comparisons underscore an additional source of uncertainty. Track stations may be most useful in presence-absence surveys or as an index for comparisons within a species when the functional relationship between track counts and population density can be assumed constant across sampling sites. As with any such endeavor, sur-

vey methods, including choice of tracking substrate and bait, should be chosen based on the goals and target species of the particular study.

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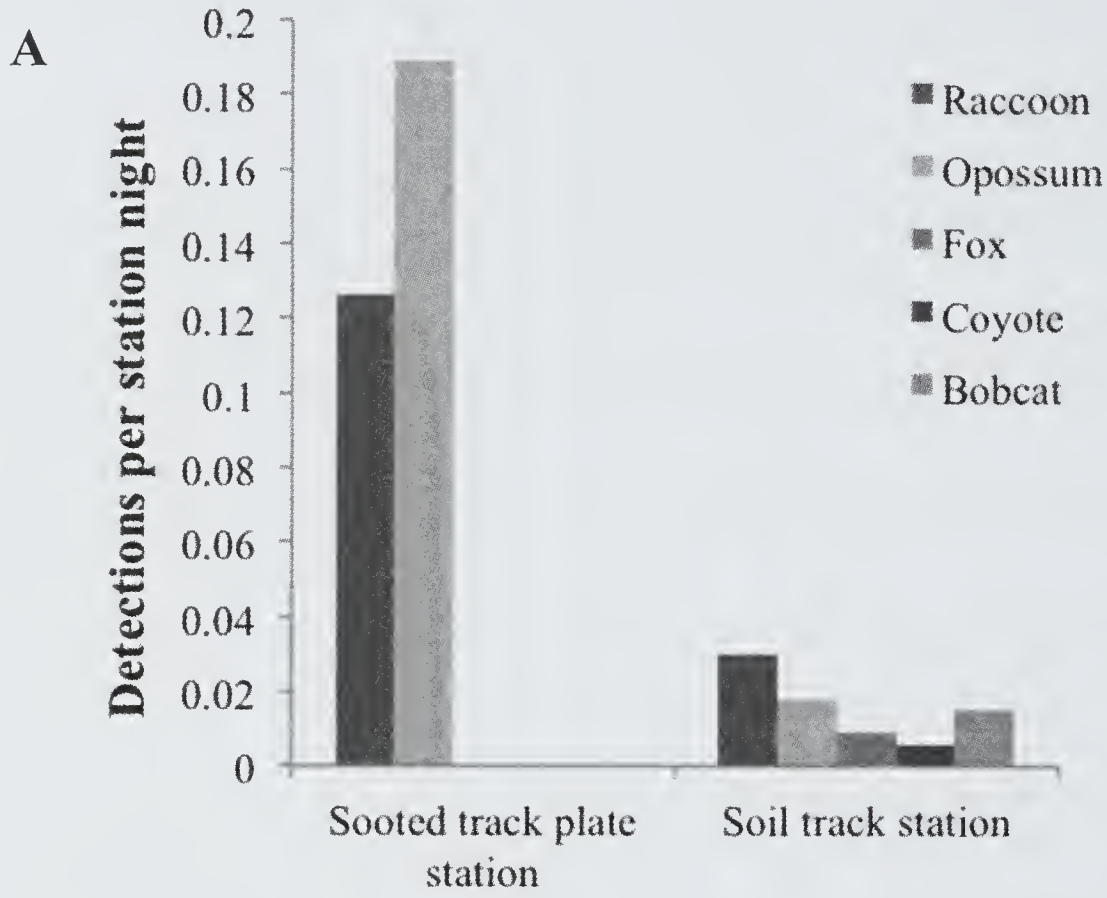
Figure 1: Detection per station night of mammalian predators by 4 noninvasive survey techniques in A) Cache River State Natural Area and vicinity, Johnson and Pulaski counties, IL (1994), and B) Middle Fork Fish and Wildlife Area, Vermilion County, IL (1995). In 1994, track plates were baited with sardines and soil track stations were baited with a commercial predator lure. In 1995, all stations were baited with pieces of raw chicken.



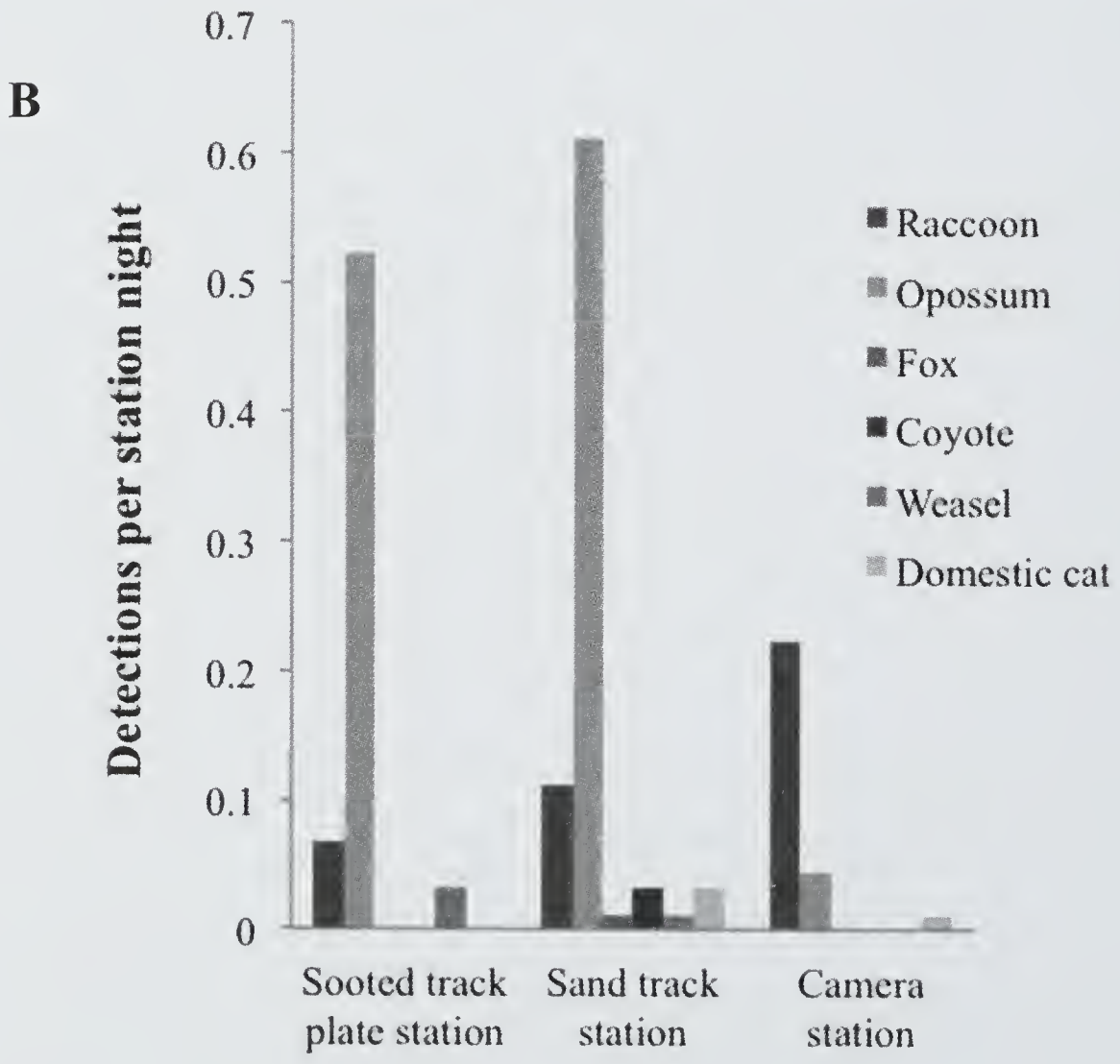


Table 1: Number and species of mammalian predators detected by noninvasive survey techniques in Cache River Natural Area and vicinity, Johnson and Pulaski counties, IL in 1994 (n=870 total station nights).

Species	Sooted track plate station	Soil track station	χ^2_1	p
Raccoon	68	10	21.66	<0.001
Opossum	102	6	38.16	<0.001
Fox	0	3	15.0*	
Coyote	0	2		
Bobcat	0	5		
Station-nights	540	330		

*Data pooled for fox, coyote, and bobcat to allow statistical analysis.

Table 2: Number and species of mammalian predators detected by noninvasive survey techniques in Middle Fork Fish and Wildlife Area, Vermilion County, IL in 1995 (n=270 total station nights). Chi-square test compares detections on sooted track stations to sand track stations only.

Species	Sooted track station	Sand track station	Camera station	Snow track survey	χ^2_1	p
Raccoon	6	10	20	3	1.0	0.317
Opossum	47	55	4	0	0.62	0.431
Fox	0	1	0	4	2.28*	0.131
Coyote	0	3	0	7		
Domestic Cat	0	3	1	1		
Weasel	3	1	0	0		
Station-nights	90	90	90	na		

*Data pooled for fox, coyote, long-tailed weasel, and domestic cat for statistical analysis. If data are only pooled for fox, coyote, and domestic cat (i.e., exclude weasel), $\chi^2_1 = 7.0$, $p = 0.008$.

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Record of a Sixteen-Year-Old White-tailed Deer (*Odocoileus virginanus*) in Carbondale, Illinois: A Brief Note

Clayton K. Nielsen, Jennifer L. Swan, and Eric M. Schauber
Cooperative Wildlife Research Laboratory
Departments of Forestry and Zoology
Southern Illinois University, Carbondale, IL 62901-6504

ABSTRACT

In May 2004, a dead white-tailed deer (*Odocoileus virginianus*) radiocollared in 1991 was found in Carbondale, Illinois, and was aged at 16 years old via cementum annuli analysis. She was a member of an unharvested, free-ranging population and likely died of natural causes. Given the average longevity of deer in unharvested populations at about 8 years of age, our finding is quite rare. Increased longevity of deer can heighten lifetime reproductive output, which may contribute to elevated deer abundance and concentrated herbivory in urban settings.

White-tailed deer are the most widespread and abundant cervid in North America (Demarais et al., 2000). When protected from human harvest, deer populations are capable of irruptive population growth given their relative longevity and high reproductive capacity (McCullough, 1979, 1997). Flower (1931) stated that deer of the genus *Odocoileus* have a mean life span of 8 years, 10 months and 6 days. Masters and Mathews (1990) recorded female whitetails surviving beyond 9 years and remaining reproductively active in an unhunted population. Relatively few records exist of free ranging white-tailed deer living >10 years (Ozoga, 1969). The oldest free-ranging deer with age determined from counts of cementum annuli was a 20-year-old female in New York state (Sauer, 1984). Thomas and Bandy (1973) analyzed teeth from 859 black-tailed deer (*O. hemionus*); their oldest animal was a 19.5-year-old female. Records of extreme longevity include accounts of captive females living to ages of 17-19 years (Rue, 1978). We are unaware of more recent reports of long-lived deer, especially in Midwestern North America.

Herein, we report finding the remains of an old-aged female white-tailed deer from an unharvested population within the city limits of Carbondale, Illinois, <1 km north of Southern Illinois University Carbondale (SIUC) property. This deer was found by researchers during May 2004 while searching for fawns as part of another study (Rohm et al., 2007, 2008). Mortality of this individual had likely occurred during the winter months (but not earlier) given the stage of decomposition. No broken long bones indicative of trauma were noted, nor was hunting legal within city limits, thus, we concluded the animal likely died of natural causes (i.e., senescence). This deer was wearing a radiocollar

(frequency 151.744 MHz) from a previous study (Cornicelli, 1992; Cornicelli et al., 1996), thus we knew the animal was captured as an adult in 1991. Remarkably, the mortality location of this individual was still within its home range as calculated by Cornicelli (1992). We collected the lower jaw from this animal and excised an incisor for analysis of cementum annuli (Gilbert, 1966). We counted cementum annuli using a microscope and concluded this animal was 16 years old, making its birth year 1988.

Old-aged deer such as this individual have important implications to population dynamics and vegetation use of deer in developed landscapes, especially if several individuals in the population are able to achieve this age. Older females will contribute fawns to the population over a longer temporal period. Although we did not study fawn recruitment rates during the entire interval this animal was alive, recruitment was estimated at 0.57 fawns/adult doe on SIUC campus during 2007 (Hubbard and Nielsen, 2011). Therefore, this animal may have produced up to 9 recruits during her lifetime, depending on how many years she was reproductively active and given that recruitment rates were similar to the 2007 estimate during 1988-2004. These simple speculations outline the importance of knowing the age-structure of deer populations, as well as adult survival and fawn recruitment rates (Woolf and Harder, 1979).

This individual apparently used a similar home range for the 15 years between her home range calculation by Cornicelli (1992) and when the deer was found dead. Lesage et al. (2000) found that deer in high-density populations coincident with suburban areas were more philopatric than those in low-density populations. Kilpatrick et al. (2001) and McNulty et al. (1997) also reported that female deer demonstrated high philopatry to home ranges even as population abundance in both areas was reduced considerably. The implications of philopatry for long-lived deer include potentially severe herbivory impacts to forage resources in a relatively small area given the long-term presence of individual deer.

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Status, Distribution, and Habitat Preferences of the Stripetail Darter *Etheostoma kennicotti* and Spottail Darter *Etheostoma squamiceps* in the Shawnee National Forest, Illinois

Jeremy S. Tiemann* and Joshua L. Sherwood[1]
Illinois Natural History Survey – Institute of Natural Resource Sustainability
University of Illinois, 1816 South Oak Street, Champaign, IL 61820
*Correspondence: jtiemann@inhs.uiuc.edu
[1]Present address: Western Illinois University, 1 University Circle, Macomb, IL 61455

ABSTRACT

In Illinois, the stripetail darter *Etheostoma kennicotti* and spottail darter *Etheostoma squamiceps* are restricted to tributaries of the Ohio River. Because of their narrow ranges, we examined the status, distribution, and habitat preferences of *E. kennicotti* and *E. squamiceps* in streams in the Shawnee National Forest, Illinois, during June 2009 to determine whether these species warrant listing under the Illinois Endangered Species Protection Act. These two fishes were the most abundant darters found and were commonly collected under slab rock and occurred in multiple basins throughout the Shawnee National Forest. Because of its high abundance and occurrence in multiple basins, we feel that neither *E. kennicotti* nor *E. squamiceps* warrant listing at this time.

Key Words: stripetail darter, *Etheostoma kennicotti*, spottail darter, *Etheostoma squamiceps,* Shawnee National Forest, Ohio River tributaries, endangered species

INTRODUCTION

The stripetail darter *Etheostoma kennicotti* and spottail darter *Etheostoma squamiceps* are diminutive (typically < 100 mm), short-lived (typically ≤ 3 years) fishes in the family Percidae, subgenus *Catonotus* (Page, 1974; Page, 1975). These sympatric species are found within the Ohio River drainage, including direct Ohio River tributaries of southern Illinois and Indiana and the Green and Cumberland river basins in central Kentucky and Tennessee (Page, 1983; Etnier and Starnes, 1993). Within Illinois, they are restricted to direct tributaries of the Ohio River (e.g., Lusk, Big Grand Pierre, and Big creeks) in the southern portion of the state (Gunning and Lewis, 1956; Simon, 1987). *Etheostoma squamiceps* is believed to be extirpated from the Little Wabash River basin (Smith, 1979), but is known from a few small direct Wabash River tributaries in Posey County, Indiana (Fisher, 2008). Also, *E. squamiceps* reported from the Cache River basin have been suggested to be misidentified fringed darters *Etheostoma crossopterum* (Poly and Wilson,

1998), and earlier references (e.g., Forbes and Richardson, 1908; O'Donnell, 1935) to *E. squamiceps* having been collected in the Kaskaskia River drainage were misidentified mud darters *Etheostoma asprigene* (Smith, 1979). The biogeographic explanation of *E. kennicotti* and *E. squamiceps* species can be attributed to geological and ecological barriers, dispersal routes, suitable habitats, and competition between species (Page and Schemske, 1978; Braasch and Mayden, 1985). Both species have been described as habitat specialists (Page et al., 1992a). They are found in small, headwater streams; *E. kennicotti* commonly occupies slab pools, whereas *E. squamiceps* typically inhabits slab riffles (Page, 1974; Page, 1975). As with most benthic fishes, darters are negatively affected by anthropogenic disturbances, including channelization, siltation, dredging, mining, oil wells, and impoundments (Page, 1983; Fisher, 2008). Neither *E. kennicotti* nor *E. squamiceps* are listed under the Illinois Endangered Species Protection Act (IESPB, 2005). The purpose of this study was to determine the status, distribution, and habitat preferences of *E. kennicotti* and *E. squamiceps* in direct tributaries of the Ohio River in the Shawnee National Forest, Illinois, and to determine whether either species warrants listing at the state level.

STUDY AREA

The direct tributaries of the Ohio River in the Shawnee National Forest, Illinois, encompass about 250 km^2 of southern Illinois (Page et al., 1992b). In this mostly forested area, the upstream stream segments flow through bluffs fed by numerous small rocky springs, whereas the lower reaches flow through deep cut banks with silt deposits over rocky substrates. These clear, free-flowing streams typically flow over coarse gravel - slab rock riffles and shallow rocky pools. The streams are relatively free of domestic and industrial pollutants but have been degraded by certain agriculture practices. The region historically supported around 80 species of fishes (Smith, 1971; Page et al., 1992b).

METHODOLOGY

Twenty-four sites were sampled in tributaries of the Ohio River in the Shawnee National Forest, Illinois, during June 2009 (Table 1). Sites were established based on habitat characteristics (e.g., rocky substrates) or historical records for *E. kennicotti* and *E. squamiceps*. At each site, at least five transects were uniformly spaced 5-m apart, perpendicular to the river channel, and up to five points were evenly established 0.5-m apart along the length of each transect. The number of transects was dependent upon the length of the run/riffle/pool sequence, and the length of transects was from bank to bank. At least 15 points were sampled per site. Fishes were collected from a 4.5 m^2 area at each point by kicking the substrate 3-m upstream from a stationary 1.5-m wide, 3-mm mesh seine and proceeding downstream to the seine in a back and forth path covering the width of the seine. To minimize disturbance, transects were sampled from downstream to upstream and points were sampled from near shore to far shore. This kick-seining method has been shown to be an appropriate quantitative method for sampling benthic fishes, including darters (Tiemann et al., 2004; Tiemann, 2008). Most fishes were identified, counted, and released upon completion of sampling at a site; at least one voucher specimen of each darter species was retained and deposited in the Illinois Natural History Survey Fish Collection, Champaign.

Subsequent to fish sampling, habitat observations were made at each point by visually assessing substrate size and composition as the percentage of clay/silt, sand, gravel, pebble, cobble/slab rock, and boulder (Tiemann et al., 2004; Tiemann, 2008). For the purpose of this paper, we combined cobble (round) and slab rock (flat) in the same size category. The fredle index was then calculated at each point at each site (McMahon et al., 1996). A high fredle index score represents the predominance of larger substrates, whereas low scores indicate smaller substrates. Mean fredle index scores of occupied points were subtracted from those of unoccupied points for each site, and the resulting values were pooled among sites. A one-sample *t* -test was then used to test for non-random use of available habitat (Gillette et al., 2006; Tiemann, 2008). If *E. kennicotti* and *E. squamiceps* randomly chose substrates then the expected value for the difference between occupied and unoccupied would be close to zero and the *t* would be non-significant; however, a significant positive *t* would indicate occupied > unoccupied and suggest that habitat is non-random. Pearson's correlation coefficient also was calculated to examine potential relationships of substrate composition percentages with *E. kennicotti* and *E. squamiceps* abundances (Tiemann, 2008). Substrate variables were arcsine–square-root transformed because they were proportional data (Zar, 1999), and sequential Bonferroni-correction of $\alpha = 0.05$ was applied to help limit the Type I error of multiple tests (Rice, 1989). Statistical analyses were performed with SAS, Version 8 (SAS Institute Inc., Cary, NC). We did not measure size of fishes; therefore, we could not differentiate among age classes for non-random use of available habitat and habitat correlations, nor could we test the theory proposed by Page and Schemske (1978) that *E. kennicotti* would be smaller with the presence of *E. squamiceps*.

Distribution models for both species were generated using georeferenced locality data, GIS environmental layers of the sample area, and the Maxent species distribution algorithm (Phillips et al., 2006). Maxent is a general-purpose machine learning approach to the modeling of species distributions using presence-only data (Phillips et al., 2006). Maxent predicts the potential distribution of a species by estimating the probability distribution of maximum entropy across a specified region, subject to a set of constraints that represent the incomplete information about the target distribution (Phillips et al., 2006). Occurrence locations of each species throughout the sample area were combined with topographic, land use, and geologic GIS data to predict suitable habitat within the sample area. Factors included in the GIS data were elevation, slope, soil association, flow accumulation, and land use data.

RESULTS / DISCUSSION

Thirty-three species from 11 families were collected at the 24 sites (329 points) sampled in the Shawnee National Forest (Table 2). A total of 313 stripetail darters were found at 17 sites and 68 spottail daters were found at 13 sites (Table 1; Table 2; Figure 1; Figure 2). We failed to find *E. kennicotti* at three historical sites and *E. squamiceps* at two historical sites (Table 1). Both darters were found throughout the Shawnee National Forest and in multiple basins, including Lusk, Big, and Big Grand Pierre creeks; Haney Creek was the only basin where we collected only one of the two target species (Table 1). Where encountered, *E. kennicotti* densities ranged from 0.01 to 0.68 indiv/m^2 (mean: 0.21 ± 0.20 indiv/m^2 SD – Table 1) and was the most abundant fish collected (Table 2) whereas, *E. squamiceps* densities ranged from 0.01 to 0.21 indiv/m^2 (mean: 0.05 ± 0.06

indiv/m^2 SD – Table 1) and was the third most abundant fish captured (Table 2). Although not sampled, both darters also are known from the Saline River basin, Illinois, and *E. kennicotti* is known from the Cache River basin, Illinois (Page and Smith, 1976; INHS Fish Collection data).

Non-random habitat use was evident for both *E. kennicotti* and *E. squamiceps*, which is common in darters (Gillette et al., 2006; Tiemann et al., 2008). These syntopic species were found in areas with higher fredle index scores (*E. kennicotti* - $t = 4.57$, $P = 0.0002$ and *E. squamiceps* - $t = 5.63$, $P < 0.0001$), which is indicative of areas with larger substrates. *Etheostoma kennicotti* abundance was positively correlated with percent gravel ($r = 0.36$, $P = 0.003$) and cobble/slab rock ($r = 0.43$, $P = 0.0002$), whereas *E. squamiceps* abundance was positively correlated with percent cobble/slab rock ($r = 0.56$, $P < 0.0001$); no other correlations were significant. *Etheostoma kennicotti* and *E. squamiceps* were seldom collected in other habitats, but both species have been known to inhabit other areas if suitable habitat is not present. *Etheostoma kennicotti* has been reported from gravel areas (Braasch and Mayden, 1985; Simon, 1987), whereas *E. squamiceps* has been recorded from woody debris and rip-rap piles (Strange, 1992; Fisher, 2008).

In order to develop and test the Maxent distribution model, locations containing each species were evenly divided into training and test groups. The training groups were used to develop the model for each species. After developing the model, the test sites were entered to quantify the predicting power of the model. Four recent (post-1990) historical locations for *E. squamiceps* were used to increase the number of locations to 17. The Maxent models for both species were significant (*E. kennicotti* - $AUC = 0.888$, $P = 0.02$ and *E. squamiceps* - $AUC = 0.954$, $P < 0.01$). Elevation (45.3%), land cover (43.3%) and soil association (11.3%) were the most important variables in explaining the distribution of *E. kennicotti* in the study area. The percent contribution of each variable in the *E. squamiceps* model was 36.2% elevation, 26.8% soil association, 23.6% slope and 13.4% land use. Land use contribution may be slightly elevated due to the inclusion of roads in the land use data and the close proximity of each sample site to a road/bridge. The results of the Maxent distribution model suggest that both species tend to favor the wooded valleys of the Shawnee National Forest. Suitable areas for both species tend to occur in areas of steep, shallow, rocky soils; streams with less of a slope and deeper soils also appear to be suitable for *E. kennicotti*. This result was most apparent in the Haney Creek basin, which contains a different soil association than most of the sample area and is the only basin where *E. kennicotti* was found in the absence of *E. squamiceps*.

MANAGEMENT CONSIDERATIONS

Neither *E. kennicotti* nor *E. squamiceps* warrant listing at this time. Although both *E. kennicotti* and *E. squamiceps* have a small distribution within the state, both species are common in several sub-basins, and the Shawnee National Forest offers ample habitat and some protection from anthropogenic disturbances. After examining the Maxent distribution model for each species, it appears that the majority of the suitable habitat in the Shawnee National Forest is already being occupied by that species. Regarding *E. squamiceps* and its affinity for specialized habitats, other studies have suggested that habitat is a limiting factor in determining the fish's distribution or reproductive locations (Bandoli et al., 1991; Strange, 1992). Because of the lack of habitat in large rivers (e.g.,

the Ohio River), populations are isolated from one another and it is unlikely that they will intermix or expand their range into new basins (Braasch and Mayden, 1985; Page et al., 1992a). *Etheostoma kennicotti*, on the other hand, can occupy a variety of habitats and has excellent dispersal capabilities (Braasch and Mayden, 1985; Etnier and Starnes, 1993). Therefore, it might be able to regionally recolonize a basin should it become extirpated (e.g., short distances within Illinois, such as from one direct tributary to another); however, Page and Smith (1976) suggested that the Ohio River is an effective barrier, so if *E. kennicotti* becomes extirpated from Illinois, it might not be able to recolonize from either the Green or Cumberland rivers.

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Table 1. Sampling locations and densities of *Etheostoma kennicotti* ('*E. kenn*') and *Etheostoma squamicpes* ('*E. squam*') during the 2009 survey in tributaries of the Ohio River in the Shawnee National Forest, Illinois. Densities are the number of individuals / meter^2. 'Hist" indicates that a historic record resides in the Illinois Natural History Survey Fish Collection, Champaign, for that species at that site.

County	Sub-basin	Stream	Latitude	Longitude	*E. kenn*	*E. squam*
Pope	Lusk	Lusk Creek	37.54469	-88.53918	0.43	0.00
Pope		Lusk Creek	37.50596	-88.53747	0.28	0.03
Pope		Lusk Creek	37.47249	-88.54800	0.16	Hist
Pope		Little Lusk Creek	37.56771	-88.50655	0.00	0.16
Pope		Trib. Little Lusk Creek	37.53390	-88.48281	0.25	0.09
Pope		Quarrel Creek	37.42534	-88.60246	0.00	0.00
Pope		Rocky Branch	37.36918	-88.54693	0.00	0.06
Pope	Big Grand Pierre	Big Grand Pierre Creek	37.58130	-88.43659	0.04	0.12
Pope		Big Grand Pierre Creek	37.48247	-88.44096	0.68	0.00
Pope		Simmons Creek	37.43196	-88.47972	0.36	0.01
Pope		Hobbs Creek	37.49784	-88.41932	0.31	0.03
Hardin		Pinhook Creek	37.56157	-88.40825	Hist	0.00
Hardin	Threemile	Threemile Creek	37.46004	-88.37715	0.00	0.02
Hardin		Threemile Creek	37.44198	-88.37355	0.12	0.04
Hardin	Big	Big Creek	37.57698	-88.30192	0.15	0.10
Hardin		Big Creek	37.53343	-88.32653	0.12	Hist
Hardin		Big Creek	37.47944	-88.34226	Hist	0.00
Hardin		Goose Creek	37.50623	-88.33540	0.10	0.10
Hardin		Hogthief Creek	37.51082	-88.27707	Hist	0.21
Hardin	Peters	Peters Creek	37.51762	-88.21803	0.00	0.00
Hardin		Peters Creek	37.48720	-88.25596	0.56	0.07
Hardin	Haney	Haney Creek	37.52301	-88.16102	0.47	0.00
Hardin		Haney Creek	37.52801	-88.11980	0.36	0.00
Hardin		Haney Creek	37.51495	-88.11093	0.29	0.00

Table 2. Fishes collected during the 2009 survey in tributaries of the Ohio River in the Shawnee National Forest, Illinois.

Family	Common name	Scientific name	No. indiv.
Clupeidae	Gizzard shad	*Dorosoma cepedianum*	8
Cyprinidae	Central stoneroller	*Campostoma anomalum*	58
	Spotfin shiner	*Cyprinella spiloptera*	19
	Blacktail shiner	*Cyprinella venusta*	1
	Striped shiner	*Luxilus chrysocephalus*	17
	Redfin shiner	*Lythrurus umbratilis*	35
	Emerald shiner	*Notropis atherinoides*	14
	Bluntnose minnow	*Pimephales notatus*	52
	Creek chub	*Semotilus atromaculatus*	46
Catostomidae	Creek chubsucker	*Erimyzon oblongus*	7
	Northern hogsucker	*Hypentelium nigricans*	12
	Golden redhorse	*Moxostoma erythrurum*	1
Ictaluridae	Yellow bullhead	*Ameiurus natalis*	3
	Tadpole madtom	*Noturus gyrinus*	2
Aphredoderidae	Pirate perch	*Aphredoderus sayanus*	17
Atherinidae	Brook silverside	*Labidesthes sicculus*	12
Fundulidae	Blackspotted topminnow	*Fundulus olivaceus*	3
Cottidae	Banded sculpin	*Cottus carolinae*	7
Centrarchidae	Rock bass	*Ambloplites rupestris*	3
	Green sunfish	*Lepomis cyanellus*	11
	Warmouth	*Lepomis gulosus*	1
	Bluegill	*Lepomis macrochirus*	7
	Longear sunfish	*Lepomis megalotis*	13
	Spotted bass	*Micropterus punctulatus*	3
Percidae	Rainbow darter	*Etheostoma caeruleum*	146
	Slough darter	*Etheostoma gracile*	2
	Stripetail darter	*Etheostoma kennicotti*	313
	Johnny darter	*Etheostoma nigrum*	12
	Orangethroat darter	*Etheostoma spectabile*	52
	Spottail darter	*Etheostoma squamiceps*	68
	Logperch	*Percina caprodes*	5
	Blackside darter	*Percina maculata*	1
Sciaenidae	Freshwater drum	*Aplodinotus grunniens*	7

Figure 1. Distribution of stripetail darter *Etheostoma kennicotti* in Pope and Hardin counties, Illinois. During this 2009 survey, solid squares indicate positive sites, open squares indicate negative sites, and solid diamonds indicated historical record (e.g., fish collected during previous surveys).

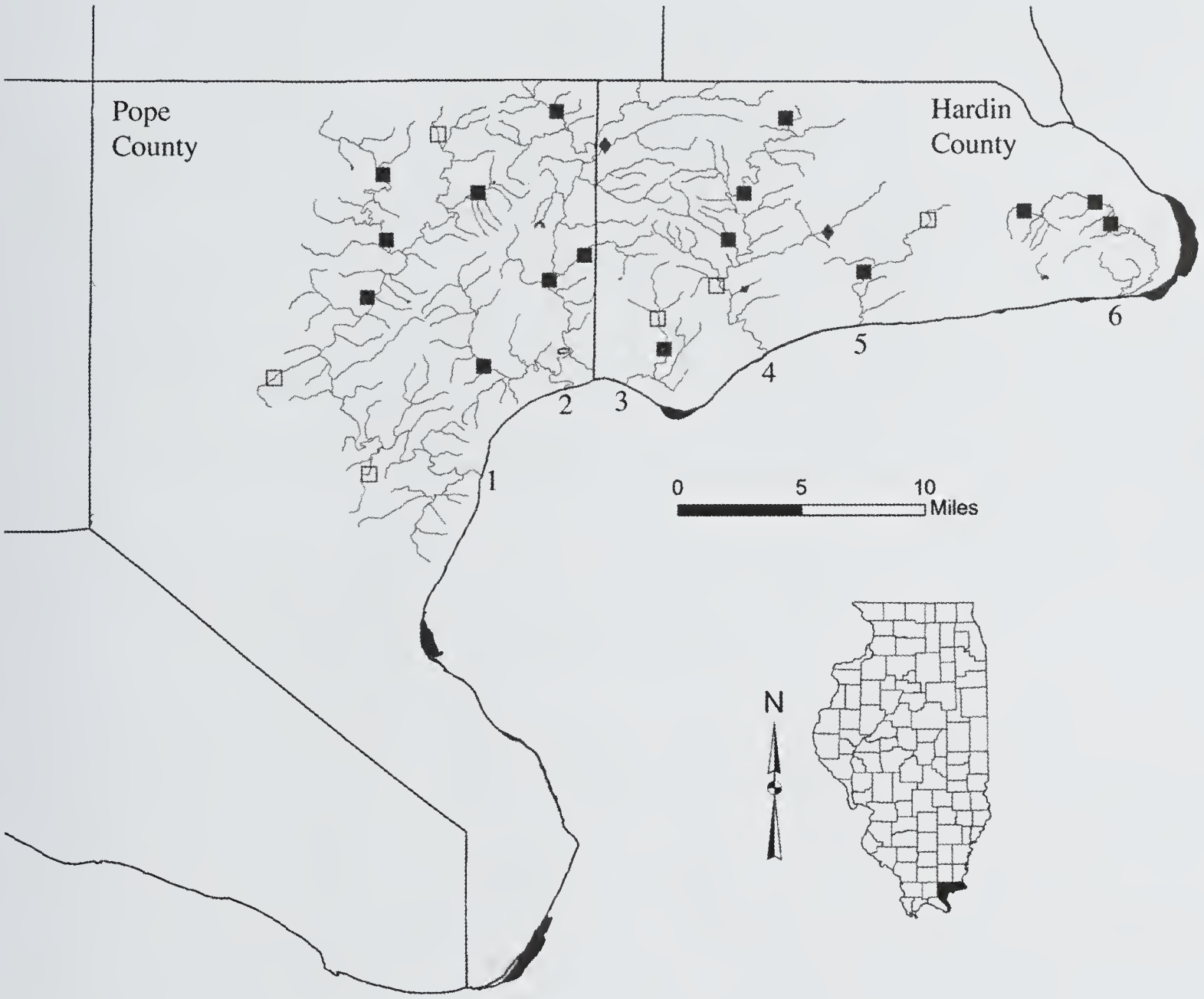
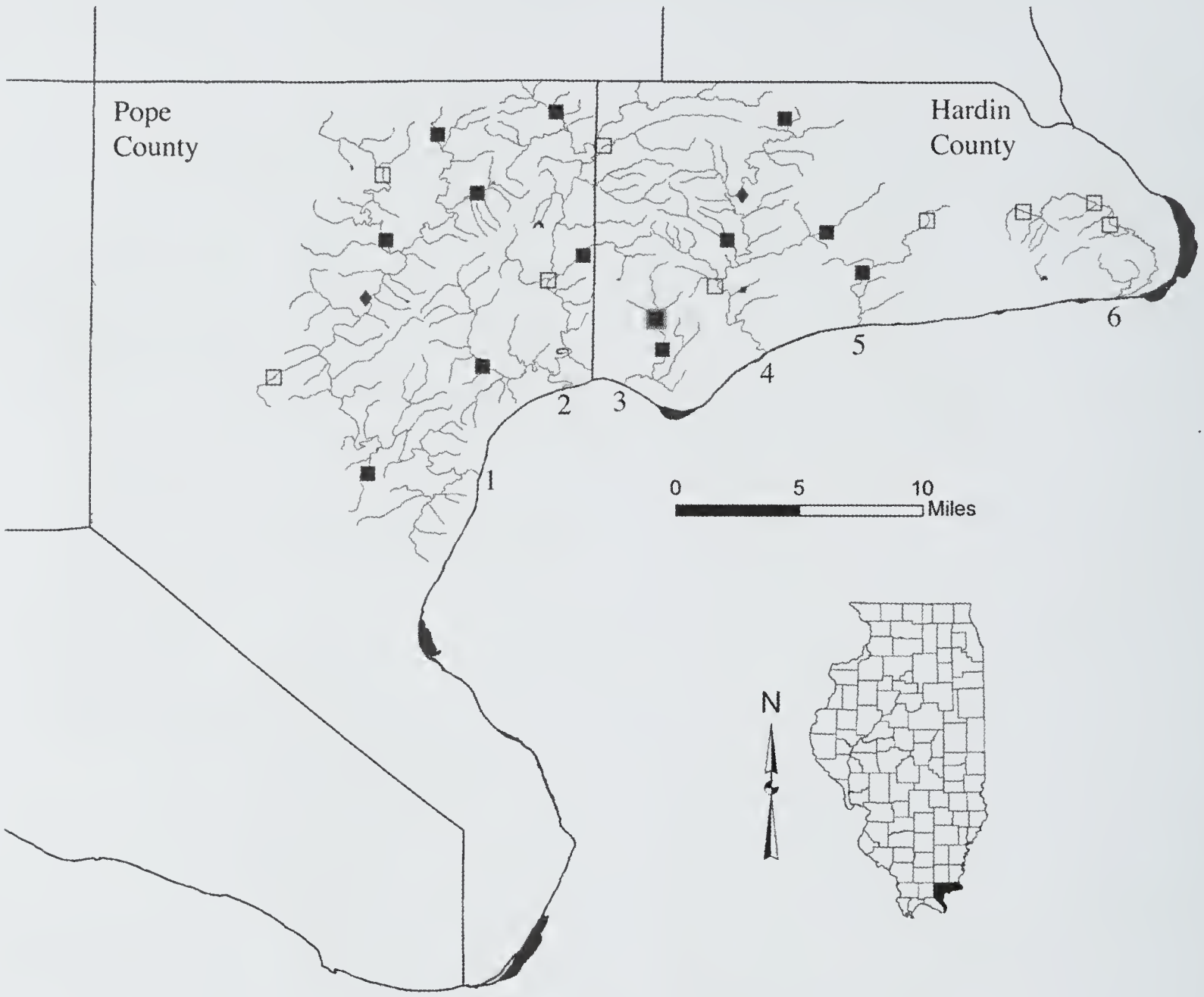


Figure 2. Distribution of spottail darter *Etheostoma squamiceps* in Pope and Hardin counties, Illinois. During this 2009 survey, solid squares indicate positive sites, open squares indicate negative sites, and solid diamonds indicated historical record (e.g., fish collected during previous surveys).



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Evidence of Cowbird Parasitism on Yellow-throated Warblers at Starved Rock State Park, Illinois, USA

Joseph A. Traina
Illinois Mathematics and Science Academy
1500 Sullivan Rd.
Aurora, IL 60506-1000

ABSTRACT

An adult yellow-throated warbler (*Dendroica dominica*) was observed feeding a fledged brown-headed cowbird (*Molothrus ater*) on July 1, 2010 at the Beehive Overlook at Starved Rock State Park (LaSalle County, Illinois, USA). Food in the form of captured insects was brought to the young cowbird five times during a period of approximately 15 minutes.

INTRODUCTION

The yellow-throated warbler's (*Dendroica dominica*) breeding range extends north to southern Wisconsin (Robbins, 1991). In Illinois, breeding records are more common to the south and are infrequent in the north (Hall, 1996). Although rates of brood parasitism by brown-headed cowbirds (*Molothrus ater*) are high in some warbler species (Ortega, 1998), there are relatively few published accounts with yellow-throated warblers as the host. Friedmann and Kiff (1985) list only four known records involving either observations of parasitized yellow-throated warbler nests or of adult warblers feeding a young cowbird: two from North Carolina, one from Ohio, and one from Oklahoma. Additional documented cases have also been reported in Florida (Cruz et al., 1998; Florida Fish and Wildlife Conservation Commission, 2003), Kentucky (Palmer-Ball, 1996), Missouri (Missouri Department of Conservation, 2011), and Tennessee (Robinson, 1997). The low frequency of observed instances of brood parasitism on yellow-throated warblers may be due, in part, to the fact that this species typically nests high in trees, making nest observations difficult (Bohlen, 1989; Hall, 1996; Robinson, 1997). Mumford and Keller (1984) report an average height of approximately 20 m for 11 nests in Indiana, and Robinson (1997) reports an average height of just over 10 m for 12 nests in Tennessee.

OBSERVATIONS

I observed an adult yellow-throated warbler feeding a fledged brown-headed cowbird within a few meters of the viewing platform at the Beehive Overlook at Starved Rock State Park (LaSalle County, IL) on July 1, 2010. The yellow-throated warbler fed the cowbird on five occasions throughout the roughly 15 minute time period during which I

made observations. The cowbird remained stationary near the main trunk on a horizontal branch of a white pine (*Pinus strobus*) as the adult warbler searched for food. The warbler either fed insects to the cowbird directly or placed the insects on the branch near the feet of the cowbird. The young cowbird immediately consumed all of the insects provided by the adult warbler. It is important to note that these observations do not automatically confirm that the yellow-throated warbler was the original foster parent of the fledged cowbird. Sealy and Lorenzana (1997) list several observations of fledged brown-headed cowbirds receiving food from more than one bird species or from a species different from that of the original host.

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Cost Comparison of Vegetation Monitoring Techniques Used to Assess White-tailed Deer Herbivory

Rachael E. Urbanek[1,4], Clayton K. Nielsen[1,2], Gary A. Glowacki[3], and Timothy S. Preuss[3]
[1]Cooperative Wildlife Research Laboratory,
Southern Illinois University, Carbondale, 62901
[2]Department of Forestry, Southern Illinois University, Carbondale, 62901
[3]Lake County Forest Preserve District, Libertyville, Illinois, 60048

ABSTRACT

Many studies investigating the effects of white-tailed deer (*Odocoileus virginianus*) herbivory on herbaceous communities have utilized plots set along browse transects or exclosures. We compared the costs (i.e., labor and construction) of using browse transects and associated 1-m^2 plots versus paired small exclosures (1.4 m diameter x 1.6 m height) and 1-m^2 control plots to monitor the effects of deer herbivory in suburban Chicago, Illinois. During May–July 2008–2009, we sampled vegetation in 2,560 quadrats along browse transects and 600 exclosed and control quadrats on eight Lake County forest preserves. Within both vegetation sampling regimes, we quantified herbivory impacts on vegetation in each sample quadrat using plant community metrics and indicator species. Using a standardized cost per sampling unit, the cost of conducting a single browse transect (i.e., 10 1-m^2 quadrats) was US $72.80 and the cost of sampling five pairs of exclosures and controls (i.e., 10 1-m^2 quadrats) using the exclosure method cost $230.60; thus, for the same amount of data, the browse transect method cost 68.4% less than the exclosure method. Managers should consider using browse transects over exclosures to assess deer herbivory when deer are not restricted from specific areas or plants. The advantages of reduced cost, increased sample size, and ability to assess large areas may outweigh the use of exclosures in these situations.

INTRODUCTION

White-tailed deer (*Odocoileus virginianus*) herbivory can have detrimental effects on ecosystems, including those vertebrates and plants that serve as indicators of major ecological changes (Casey and Hein 1983; Anderson 1990; Flowerdew and Ellwood 2001; Smit et al. 2001; Frankland and Nelson 2003; Greenwald et al. 2007). Compared to woody vegetation investigations, few studies have assessed the impacts of deer herbivory on herbaceous plant communities (Anderson 1994) and limited vegetation monitoring methods exist. Several studies have monitored structural components of sole indicator species (Anderson 1994; Augustine et al. 1998; Augustine and Frelich 1998; Knight 2003; Farrington et al. 2004; Webster et al. 2005) or a few select species of interest (Englund and Meyer 1986; Augustine and Jordan 1998; Webster and Parker 2000; Webster et al. 2001; Frankland and Nelson 2003; Rurhen and Handel 2003). Fewer studies have broadly monitored all browsed species and plant community metrics such as species

richness and species evenness to assess widespread impact of deer herbivory on plant communities (Anderson et al. 2001; Frankland and Nelson 2003; Anderson et al. 2005; Webster et al. 2005). Regardless of which plant community metrics or species are monitored, most deer herbivory studies utilize exclosures or browse transects to collect data in sample plots.

Exclosures are broadly described as fenced areas and are often used in white-tailed deer herbivory studies (Englund and Meyer 1986; Anderson 1994; Augustine et al. 1998; Anderson et al. 2001; Rurhen and Handel 2003; Anderson et al. 2005; Webster et al. 2005). Researchers assess deer herbivory by comparing structural aspects (e.g., stem height, number of flowering stems, leaf width) of floral communities observed in the control plots exposed to herbivory versus those within exclosures. Sampling methods within large exclosures include single large (3.7–10m^2) sample plots (Englund and Meyer 1986; Augustine et al. 1998; Rurhen and Handel 2003; Webster et al. 2005) or use of transects or randomized sampling within exclosures to delineate small (25cm^2–1m^2) sample plots (Anderson 1994; Anderson et al. 2001; Anderson et al. 2005).

Few researchers have used small exclosures to assess white-tailed deer herbivory (Augustine and Frelich 1998; Augustine et al. 1998; Frankland and Nelson 2003). With large exclosures, bias exists because plants are associated with one another and large exclosures may not contain browsed species from a different portion of the study site (Frankland and Nelson 2003). Additionally, researchers risk simple pseudoreplication if they are only comparing one exclosure and one control (Hulbert 1984). Thus, smaller (≤1m^2), but more abundant, exclosures are preferable to increase sample size and reduce bias. In addition, small exclosures are less expensive, may be collapsible for storage and transport, and allow for greater coverage of study sites (Frankland and Nelson 2003). Small exclosures have been used to fence individual plants (Augustine and Frelich 1998) or enclose small populations of a specific species (Augustine et al. 1998). Alternatively, Frankland and Nelson (2003) used 30 1-m^2 exclosures with paired controls to monitor portions of entire vegetation communities.

Browse transects also have been used to assess white-tailed deer herbivory on woody vegetation (Pitt and Schwab 1990; Doenier et al. 1997), yet this technique is scarcely applied to assess the effects of deer herbivory in herbaceous communities outside of exclosures. In general, this method involves sampling vegetation along multiple transects. When browse transects have been employed, several methods have been utilized to assess the impacts of deer herbivory. Augustine and Jordan (1998) examined the percent browsed, percent unbrowsed, and percent flowering of seven early-summer forb and seven late-summer forb species using 6-m^2 circular plots spaced 25–50 m apart along transects. Augustine and Frelich (1998) used 2-m and 4-m strip transects to investigate browse damage on trillium (*Trillium* spp.) communities. Similarly, Knight (2003) used 1-m^2 plots randomly placed along transects through trillium populations to assess browse damage. Alternatively, Webster and Parker (2000) and Webster et al. (2001) used three 10-m long transects to quantify percent cover of herbaceous forbs.

The quality of data gained from either vegetation sampling method can be variable, if not questionable. Many researchers rely on exclosures and paired controls because they believe it results in higher quality data due to its experimental setup. However, compari-

sons of individual species and plant community metrics found in exclosure and control plots may not indicate the overall effect of deer herbivory at a site. Observations inside an exclosure do not necessarily depict how the plant community would appear in the absence of deer herbivory but rather contain vegetation that is in a stage of recovery (Suzuki et al. 2008). Further, it may take several years after the construction of exclosures to see significant differences between exclosure and control plots due to the legacy effects of chronic deer browsing (Russell et al. 2001; Banta et al. 2005; Royo et al. 2010; Urbanek et al. 2012*a*). In addition, researchers must consider the effects of light depletion on plants within exclosures due to exclosure material creating shadows. Hence, researchers must be cautious when drawing conclusions from observed differences between exclosures and control plots.

Similarly, researchers must be equally cautious when using data collected from browse transects. Without control plots, multiple sites or years are required to gain any valuable data. When multiple sites are involved, researchers should be aware that differences in abiotic factors may conflate results. However, if researchers are only interested in overall differences between sites over time, data on stem heights or plant community metrics can be assessed as indices to monitor trends. Thus, obstacles exist for both vegetation monitoring methods, but both exclosures and browse transect methods can provide the same quality data if studies are well designed.

We assessed white-tailed deer herbivory on eight Lake County forest preserves near Chicago, Illinois (Urbanek and Nielsen 2010, Urbanek et al. 2012*a*,*b*). We compared the advantages, disadvantages, and cost of using browse transects and exclosures in four different plant communities. The objective of this study was to provide managers with information regarding which technique is most beneficial to use given a situation when both deer herbivory monitoring methods are applicable (i.e., no need to restrict deer from an area).

STUDY AREA

Lake County, Illinois, is located approximately 40 km northwest of downtown Chicago, has >703,462 inhabitants, and is <1,200 km^2 in area (USCB 2010). The Lake County Forest Preserve District (hereafter, the District), created in 1958, consists of >10,800 ha in 57 preserves that provide a combination of natural, recreational, educational, and cultural resources for county residents and tourists. The District identifies separate plant communities within its preserve system as characterized by the Chicago Wilderness Terrestrial Classification System (CRBC 1999): forests contain >50% canopy cover, savannas have 10–50% canopy cover, and prairies and wetlands consist of canopy cover <10%.

METHODS

Exclosure Methods

The following are modified methods from Urbanek et al. (2012*a*) and Urbanek and Nielsen (2010). During 2007-2009, we used exclosures to compare the effects of deer herbivory in two forest and three savanna sites with known overwintering deer densities (Urbanek et al. 2012*a*). In 2008 and 2009, we sampled vegetation in a 1-m^2 quadrat in

150 exclosures and 150 control plots each year, thus 600 1-m^2 quadrats were sampled via this method during the course of study.

On each site, we constructed 30 small (1.4 m diameter x 1.6 m height) deer exclosures during June–August 2007 with 5.4 x 1.6-m rectangular pieces of fixed-knot 12.5-gauge (ga) wire STAY-TUFF® horse fencing (Stay-Tuff Fence Manufacturing, Inc., New Braunfels, Texas, USA) by bending the pieces to form circular exclosures with approximately 1.4-m diameters. This size allowed for a 1-m^2 quadrat to fit within the exclosure with a 0.2-m unbrowsed buffer to allow deer browsing in the periphery of the exclosure. The horizontal spacing between stay wires gradually diminished from 18 cm at the bottom to 8 cm at the top and the vertical distance between line wires remained constant at 15 cm. This design allowed for smaller browsing animals (*e.g.*, eastern cottontails [*Sylvilagus floridanus* Allen], woodchucks [*Marmota monax* L.]) to enter the exclosure in the larger spacing at ground level while deterring deer from browsing at the top. Exclosures were tied with 16-ga wire to three 1.2-m posts staked at angles from each other for stability.

Exclosures were spaced in each site in a grid design approximately 60 m from any neighboring exclosure and 30 m from any road, path, railroad or habitat edge. A 1-m^2 control plot was located 30 m away from each exclosure at an azimuth of 225° to accommodate all control plots within the designated study area. Control plots were also ≥30 m from any other exclosure, road, path, railroad or habitat edge.

We collected plant measurements within exclosures and control plots during 1–30 June, 2008–2009. We began collecting data in the southernmost preserve and worked in a northernly direction among preserves. This accounted for the approximate 2-week temporal difference in plant growth among similar species in preserves on opposite sides of the county (K. Klick, Lake County Forest Preserve District botanist, pers. comm.). We used similar deer browse measurements as found in the literature (Anderson 1990, 1994; Augustine and Frelich 1998; Webster and Parker 2000; Frankland and Nelson 2003). All herbaceous plants found within the control quadrats were identified and number of individual ramets (hereafter, plants) of each species was tallied. The number of plants browsed by deer was quantified per species and height (cm) was recorded for each individual. We only included browsed plants that we were 100% confident were browsed by deer and not by any other animal. Plants browsed by deer were identified by jagged edges as opposed to rodent browse which tends to be angled and clean-cut (Anderson 1969; Hygnstrom et al. 1994). Stem height was measured as the distance from the ground to the apical meristem or end of the remaining stem. We identified and quantified the number of individual plants of all species in exclosure quadrats. The stem height of all species browsed in the control quadrats were measured in the exclosure quadrats. In both exclosures and control quadrats, we estimated percent cover of non-vegetated soil, grass and sedge.

Browse Transect Methods

The following are modified methods from Urbanek et al. (2012*b*) and Urbanek and Nielsen (2010). During the study, we sampled 256 browse transects in two forest, two savanna, two prairie, and two wetland sites with known overwintering deer densities

(Urbanek et al. 2012*b*). On each browse transect, we sampled vegetation in 10 1-m^2 quadrats, thus 2,560 1-m^2 quadrats were sampled via this method during the course of study.

Eight browse transects were conducted in each community type during 1–31 May and 1–31 July of 2008 and 2009, resulting in 128 transects monitored each year. Transects conducted in May were used to assess spring ephemerals and early-stages of other forbs and July transects were used to assess herbaceous plants growing throughout the summer season. We created polygons that encompassed the respective plant community for each preserve using ArcMap software (ESRI Corporation, Redlands, California, USA) and used Hawths Tools to randomly place 100-m-long transects throughout the polygons in each preserve. All transects were placed ≥30 m away from any road, path, railroad or other transect.

Similar to the exclosure methods, we began collecting data in the southernmost preserve and worked in a northernly direction among preserves. A measuring tape was used to mark the center of each transect and at every 10-m mark (e.g., 0 m, 10 m, 20 m) a random 4-digit number was chosen to locate where the 1-m^2 sample quadrat was placed. The first two digits determined the direction and distance (m) the observer moved along the transect. Even numbers specified forward progress and odd numbers indicated the observer went backwards along the transect. The second two digits determined the perpendicular distance (cm) the center of the quadrat was placed away from the right of the transect.

All herbaceous species were identified and number of plants were tallied within each quadrat. For each browsed species, average height (cm) was collected using methods similar to Webster and Parker (2000) and Webster et al. (2001). The 10 largest flowering plants closest to the center of the quadrat were measured from the ground to the apical meristem. If 10 flowering individuals could not be found within the quadrat, the 10 largest plants closest to the center were measured. If <10 plants were found within the quadrat, all plants were measured. We also quantified the total number of plants browsed per species and approximate percent cover of non-vegetated soil, grass, and sedge within each quadrat. After data collection, the observer walked to the next 10-m mark and repeated this procedure, but placed the quadrat on the left of the transect to ensure that each quadrat was placed on alternating sides along the transect until 10 quadrats were sampled.

Cost Comparison

We recognize survey costs and hourly labor costs may change over time; thus, we were more interested in the difference in cost between the 2 techniques which we reasoned would remain similar over time. We used an hourly wage of $10/people-hour for the cost calculations of both vegetation monitoring techniques. For browse transects, costs included only labor to sample the vegetation because no specialized equipment (i.e., items not typically readily available at an agency) was required. For exclosures, costs included specialized equipment (Table 1), construction labor, and sampling labor. We adjusted the people-hours required for sampling the exclosures and control quadrats to the average time it took to sample a quadrat using the browse transect methods (19 min/observer) to correct for differences in stem height measurement methods. We then standardized costs per 1-m^2 quadrat for each vegetation sampling regime to facilitate direct comparisons between techniques. Finally, we calculated the total cost and

standardized costs for each technique over a 1, 2, 3, 4, 5, and 10-year study to determine if and when the costs would merge (Table 2). For these calculations, we kept labor costs constant (i.e., $10/hr) and did not include any maintenance charges for the exclosures.

RESULTS

Conducting 256 browse transects cost US $18,650 (1,865 people-hours at $10/hr). For exclosures (Table 1), we spent $3,127 on equipment and $10,710 in labor costs, which brought the grand total cost to $13,837. Using a standardized cost, a single 1-m^2 quadrat via the exclosure study design ($13,837/600 quadrats) was $23.06, whereas the cost to sample a single 1-m^2 quadrat via the browse transect method ($18,650/2,560 quadrats) was $7.28. Accordingly, sampling five pairs of 1-m^2 quadrats (i.e., 10 1-m^2 quadrats) using the exclosure method cost $230.62, whereas the cost of sampling a single browse transect (i.e., 10 1-m^2 quadrats) was $72.80. Given a 10-year study, the standardized per-quadrat cost of the browse transect method would still be 32% less expensive than using the exclosure method (Table 2).

DISCUSSION

Exclosures and browse transects are both useful vegetation monitoring techniques for assessing white-tailed deer herbivory and both methods have advantages and disadvantages. We found that for the same quantity of data (i.e., 10 1-m^2 quadrats) the browse transect method cost 68% less than the exclosure method. Exclosures studies can be more expensive due to the initial construction and labor expenses. Proper fencing material (e.g., large gauge wire) must be sturdy enough to withstand local weather and any damage deer may cause from pushing against the structure. In contrast, browse transect costs are substantially lower because this method has no initial building expenses and the necessary equipment (i.e., a meter tape) is usually already available. Even given a long-term study, the initial costs of exclosures incur a legacy effect on total costs for over a decade.

In addition to a higher cost, there are several other disadvantages to using exclosures. First, managers often use large exclosures for their deer herbivory assessments which can lead to a strong bias (Frankland and Nelson 2003). Thus, smaller, but more abundant, exclosures are preferable to increase sample size and reduce bias (Frankland and Nelson 2003), yet this also increases costs. In addition, sample size may be limited with traditional metal or wood exclosures due to difficulty associated with constructing exclosures in rugged or remote terrain. Second, exclosures require maintenance to repair damage from factors like weather and vandalism; hence, further long-term costs may be incurred. Third, exclosures detract from the natural setting of the land, especially if left unmaintained. Large metal or wood exclosures are often laborious to move and manipulate regularly and are thus usually left in the same spot where they were originally constructed. In summary, exclosure studies are more expensive, may be biased if only large exclosures are used, and the structures could be an eyesore to visitors of natural areas.

Exclosures do have two primary advantages over browse transects. First, exclosures that are maintained (i.e., regularly fixed and checked for structural integrity) can support long-term studies that may provide stark comparisons between chronically browsed and unbrowsed sites. Second, exclosures provide means for two-way analyses if researchers

seek to compare both the effect of different white-tailed deer densities (i.e., comparison of different sites) and the absence of deer browse (Urbanek et al. 2012*a*). Similarly, exclosures may also provide data for other analyses if deer herbivory research is conducted on a single site and in only one year whereas the browse transect method would require multiple years of data collection for a comparable analyses on a single site. However, if multiple sites with known deer densities are monitored in a given year, comparisons can be made among sites using browse transects to determine the effect of deer density and subsequent browse on plants (Urbanek et al. 2012*b*).

Comparatively, browse transects have some advantages over exclosures besides a reduced cost. Unlike exclosures, sample sizes are not limited with this method because transects can be laid anywhere in the study site including places that may be unsuitable for exclosures. Additionally, the browse transect method creates less disturbance to the natural setting because no unnatural structures are required.

IMPLICATIONS

Natural resource managers should be concerned with the advantages, disadvantages, and cost of browse transects and exclosures when considering which method to use to assess white-tailed deer herbivory. This is especially true given a situation where deer do not need to be restricted from an area and no prior exclosures have been constructed. In these cases, we recommended managers consider using browse transects due to the advantages of reduced cost, increased sample size, and ability to assess large areas.

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Table 1. Incurred costs of using exclosures to monitor white-tailed deer herbivory in Lake County, Illinois, 2007-2009.

Equipment and labor	Cost
Equipment	
Specialized fencing	$1,992.00
Fence cutters	$113.00
U-posts	$760.00
Wire for tying u-posts to fencing	$32.00
Equipment shipping and delivery	$230.00
Total equipment costs	$3,127.00
Labor ($10/people-hr)	
Construction labor (618 people-hours)	$6,180.00
Sampling labor (453 people-hours)	$4,530.00
Total labor costs	$10,710.00
Grand total	$13,837.00

Table 2. Projected costs (USD) of vegetation monitoring techniques to assess white-tailed deer herbivory in Lake County, Illinois 2007-2009. Labor costs were held constant ($10/hr) and no cost of maintenance to exclosures was included.

Years of study	Browse transect method			Exclosure method		
	Total cost	Total # of quadrats sampled	Standardized cost	Total cost	Total # of quadrats sampled	Standardized cost
1	$9,325	1,280	$7.28	$11,572	300	$38.57
2	$18,650	2,560	$7.28	$13,837	600	$23.06
3	$27,975	3,840	$7.28	$16,102	900	$17.89
4	$37,300	5,120	$7.28	$18,367	1,200	$15.31
5	$46,625	6,400	$7.28	$20,632	1,500	$13.75
10	$93,250	12,800	$7.28	$31,957	3,000	$10.65

FUTURE MEETINGS

104th Annual Meeting of the Illinois State Academy of Science

March 30-31, 2012

Knox College, Galesburg IL

105th Annual Meeting of the Illinois State Academy of Science

2013 – TBA

NOTES

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